Work Project

Country-specific Drivers of Triadic Patent Families in selected environment-related Technologies

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A country-level empirical research on environmental innovation activity

NOVA

School of Business & Economics

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Acknowledgement

Firstly, I would like to express my sincere gratitude to my first supervisor Nina Karthaus, member of the Organisation and Strategy Department at Maastricht University School of Business and Economics. Without her valuable knowledge and continuous support throughout the entire process of writing, this master thesis would not have become what it is now. While providing clear guidance, she simultaneously afforded me to work independently and conduct my own research. I am grateful for her continuing engagement, constructive advice, as well as for her amiable nature which combined created an ideal work environment.

Further, I would like to acknowledge Professor Dr Iwan Bos, member of the Organisation and Strategy Department at Maastricht University School of Business and Economics, as the second reader of this thesis. In the same vein, I would like to acknowledge Professor Dr Miguel Muñoz Duarte as well as Teresa Mannebach as being my supervisors at NOVA School of Business and Economics. I am gratefully indebted to their insightful comments on this research.

I am also grateful to my brother William Virnich for always being amenable to share thoughts and ideas and, thus, for stimulating discussions in the course of writing this thesis. Similarly, I want to express my deep appreciation for my girlfriend Carolin Vosdellen who always stands by my side giving me warm encouragement and exercising continued patience.

Finally, I would like to express my very profound gratitude to my mother Marie-Luise Virnich and Wolfgang Lehwald for giving me the chance to participate in the Double Degree Program, in the first place. Moreover, they have provided me with unfailing support and persistent encouragement throughout my years of study and especially through the process of researching and writing this thesis. This accomplishment would not have been possible without them so that I dedicate this thesis to them. Thank you!

Abstract

The importance of innovation in being a driving force for national economic development is broadly acknowledged by a large body of literature. Especially, the development of environmentally friendly technologies and services has transformed into a growing industry and, thus, gained in influence on economic growth patterns. Motivated by differences in eco-innovation performance across OECD economies, the present study provides new evidence on country-specific determinants of environmental related innovation activity. Using panel data setting of 28 OECD countries concerned over the period 1998 – 2013, the analysis builds upon theoretical grounds of ideas-driven endogenous growth theory as well as the national innovation system (NIS) perspective and examines the relationship between determinants of five innovation conditions and environmental innovation output. Particularly, the study integrates separate literature strands regarding institutional-, human capital and research-, infrastructure-, market sophistication- and business sophistication conditions into a single model. Referring to Triadic Patent Families in selected environment-related technologies, the thesis employs an empirical operationalisation of eco-innovation that improves international comparability compared to commonly used patent counts from single patent offices. Using fixed effects regression models, empirical results suggest that governmental expenditures on education, credit availability to the private sector, and inward foreign direct investments play a role in determining national environment-related innovation performance. In contrast, no evidence is found for a significant impact of factors regarding institutional- as well as infrastructural innovation conditions.

Keywords: Eco-innovation; Triadic Patent Families; National innovation system; Innovation drivers; Fixed effects regression

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1. Introduction

Varying terminology is used in attempting to define environmental innovation. The thesis considers the terms “environmental-”, “green-“, and “eco-innovation” as interchangeable and identical. They are understood as any form of innovation that results in the reduction of environmental impacts irrespective of the innovator’s original intention (Organisation for Economic Co-operation and Development [OECD], 2010; Rio, Penasco, & Romero-Jordan, 2016). Looking at national environmental innovation output, it becomes apparent that the commercialisation of technology related to environmental pollution, water scarcity, and climate change mitigation has been concentrated in only few countries while, further, being subject to fluctuations over time. Taking into consideration recent patent data from 2013, France, Germany, and the UK, for instance, stand at the forefront in terms of patenting activity at the beginning of the twenty-first century as illustrated by Figure 1. The questions arise why there are cross-country differences in the intensity of eco-innovation and why this intensity fluctuates over time.

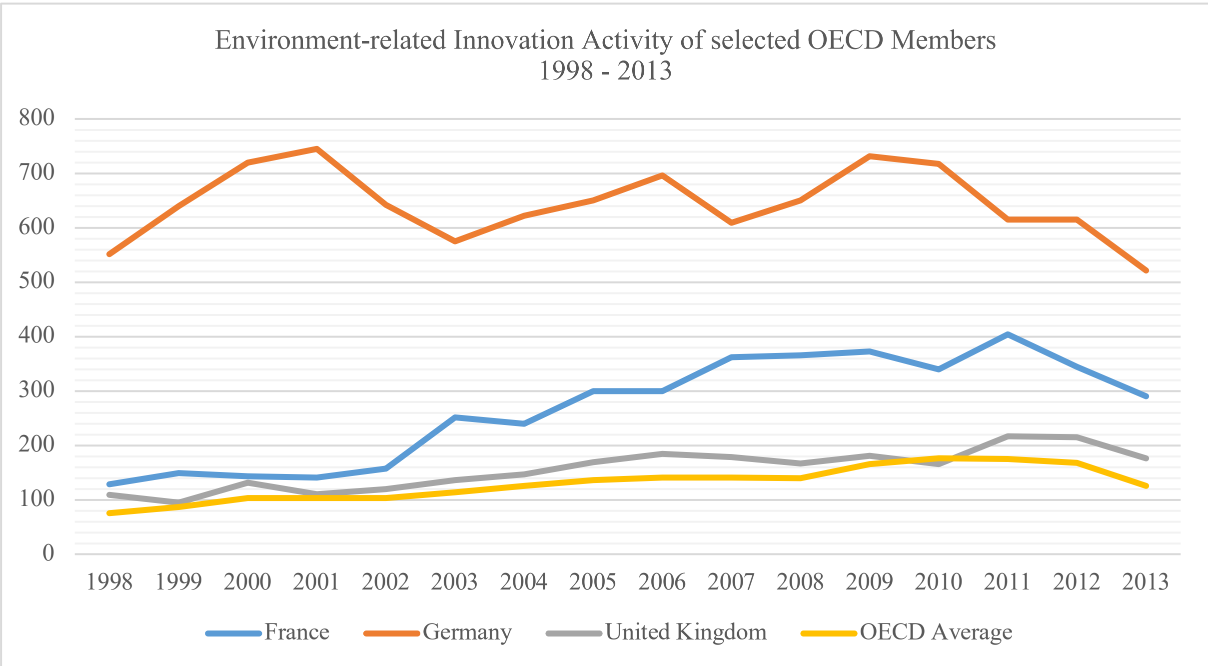

Figure 1. Environment-related Innovation Activity of selected OECD Member States 1998 – 2013. Environmental related innovation activity measured by OECD Triadic Patent Families in selected environment-related Technologies. OECD Average based on 36 OECD member countries as of December 2018.

Importance of these questions can be explained from a societal point of view on the one hand as well as from an economic perspective on the other. Firstly, our society enforcedly is in need of nurturing environment-related innovation since the modern world is generally confronted with challenges that can only be overcome by fundamental inventions in technical, ecological, social, and economic fields (European Commission, 2017; Haščič & Migotto, 2015). Especially in view of an ongoing climate change, main challenges become manifest in the transition to a clean, efficient and sustainable energy system, the realization of a resource-efficient economy, the achievement of a smart, green and integrated transport system, or the protection of natural resources and ecosystems as outlined by the European Commission (2017). To manage these challenges, it is of utmost relevance for the well-being of society to understand how to efficiently foster innovation activity on a global scale. At the same time, it should be acknowledged that environmental performance may not be the initial driver. That is, secondly, the ability to continually innovate emerges to be a key success factor in today’s complex and dynamic economy as emphasized by research of endogenous growth theories (Filippetti & Archibugi, 2011; Furman, Porter, & Stern, 2002; Hu & Mathews, 2005; Khayyat & Lee, 2015). Accordingly, national governments increasingly place innovation at the centre of their growth strategies (Dutta, Lanvin, & Wunsch-Vincent, 2018), highlighting its economic importance. A country’s capacity to compete is becoming a question of a country’s capacity to innovate (Constantini, Crespi, Marin, & Paglialunga, 2017). The Organisation for Economic Co-operation and Development (2011) especially emphasises contribution potential of environmental innovation to economic development showing that the management of climate change and associated environmental goods and services has transformed into a rapidly growing industry inevitably offering huge profit potential. Consequently, decision-makers in economy, politics, and sciences are in search of significant innovation determinants to develop appropriate policies that foster environmental inventive activity (Haščič & Migotto, 2015).

The pursuit and development of policies intending to facilitate environment-related, national innovation activity effectively, however, are consistently limited for at least three reasons. Firstly, while a considerable amount of existing research has focused on the importance of national innovation capability for economic performance (Khedhaouria & Thurik, 2017), empirical literature specifically examining national antecedents of environment-related innovation seems to be still in its infancy (Díaz-García, González-Moreno, & Sáez-Martínez, 2015; Klewitz & Hansen, 2013; Rio, Penasco, & Romero-Jordan, 2016) mainly because of data restrictions (Horbach, 2014). For instance, patent data of environment-related technologies as a proxy for environmental innovation activity has been made available only recently (Haščič & Migotto, 2015). Secondly, existing empirical literature pertaining to determinants of national innovation capability does not provide a single holistic framework covering all relevant dimensions of innovation drivers (Filipetti & Archibugi, 2011; Khayyat & Lee, 2015; Kirikkaleli, Ozun, & Sari, 2018). This can be ascribed to the fact that existing studies seem to be rather fragmented and exclusively focus on a fractional amount of those innovation conditions which are deemed to be relevant by other authors (Khedhaouria & Thurik, 2017). Thirdly, empirical literature is insufficient in that it does not agree on a harmonised set of underlying drivers of the innovation process (Furman, Porter, & Stern, 2002; Filippetti & Peyrache, 2011; Castellacci & Natera, 2013) which is in turn caused by point one and two as outlined above.

Motivated by this important gap, the central purpose of this study is to deliver novel insights into the literature of environment-related innovation drivers, firstly, by availing itself of updated and more sophisticated data. Generally, it is recognised that patent counts are the most useful measure available to examine technology output and to compare its changes across countries and over time (Nam & Barnett, 2011; Lee, Nam, Lee, & Son, 2016). Following Popp (2005), though, patent counts from single patent offices do not represent a precise comparison of innovative activity across countries by reason of a home advantage bias. This bias occurs since domestic patent applicants tend to file patents in their home country first, before filing at foreign patent offices (Dernis & Khan, 2004). The study utilises recently published OECD Triadic Patent Family (TPF) database in order to avoid this bias. That is, a set of patent applications for the same invention filed at the European Patent Office (EPO), the United States Patent and Trademark Office (USPTO) and the Japan Patent Office (JPO) are considered in the analysis. This way, the research explicitly contributes to the cross-country empirical literature by enabling improved international comparability and accentuates its uniqueness. Data is further disaggregated into specific technology fields and allows to concentrate on those technologies that address environmental pollution as well as water scarcity and facilitates eco-system health and climate change mitigation. Secondly, the thesis helps to address aforementioned gap and justifies its novelty by developing a comprehensive framework which covers a broader spectrum of pertinent dimensions compared to past research. Thus, drawing on the ideas-driven endogenous growth theory and the national innovation system perspective, a model will be developed that consolidates innovation drivers in five dimensions being institutions, human capital and research, infrastructure, market sophistication, and business sophistication. Thirdly, taking a practical perspective, the study provides an empirical model to inform governments as well as international organisations how to manage national environmental innovation output significantly. Therefore, the thesis builds on the research question of what macro-level indicators determine national environmental-related innovation. In particular, it examines in how far conditions concerning institutions, human capital and research, infrastructure, as well as market- and business sophistication will affect national eco-innovation activity.

This thesis attempts to answer the research question by firstly examining the state of existing literature and providing an overview of what research has discovered so far. On this basis, a comprehensive theoretical framework will be developed, and hypotheses will be inferred in

Section 2. Subsequently, data descriptions will be provided as well as different models for estimating national innovation activity will be depicted in Section 3, conjointly capturing the methodology. Then, analysis results will be revealed before being tested for robustness in Section 4. After a thorough discussion of the findings including political- and theoretical implications, limitations as well as future research opportunities in Section 5., Section 6 will close the paper with an overall conclusion.

2. Theoretical Framework

This section aims to theoretically develop and ground underlying hypotheses of the research study. For this reason, ideas-driven endogenous growth theory and the national innovation system perspective will be introduced in the first place, serving as the theoretical foundation for argumentation. A conceptual framework, derived from theory, is depicted in Appendix A. Subsequently, a clear line of arguments will be provided explaining the composition of relevant variables used in the theoretical framework (Appendix B). In order to ensure coherence, the discussion of research studies is grouped according to five pillars being institutions, human capital and research, infrastructure, market- and business sophistication.

2.1 Endogenous Growth Theory and National Innovation System (NIS) Perspective

The thesis draws on two individual areas of previous research, which become manifest in the ideas-driven endogenous growth theory on the one hand and research on national innovation system on the other. Both research areas classify country-specific factors that influence innovation performance. Whereas endogenous growth theory generally points to investment in human capital and knowledge in the form of subsidies for research and development or education in order to offer incentives for innovation, the NIS perspective highlights a wider spectrum of nuanced factors (Furman, Porter, & Stern,2002). Freeman (1982) was pioneering by proposing the concept of the national innovation system in the 1980s. With his work, he intends to challenge the neoclassical concept of economic growth as it disregards the role of innovation and technological development. In general, a national innovation system can be described as a subsystem of a country's economy in which institutions and organisations collectively engage in inventive activities (Balzat & Hanusch, 2003). In fact, literature of both research areas agrees by arguing that innovation and technological change are decisive factors for economic growth (Filippetti & Archibugi, 2011; Furman, Porter, & Stern, 2002; Khayyat, & Lee, 2015; Khedhaouria & Thurik, 2017; Lundvall, 1985, 1988; Nelson, 1988, 1990). Amongst others, the authors base their reasoning on research conducted by Nelson and Winter (1982) and the neo-Schumpeterian theory of innovation stating that economic growth is nurtured by evolutionary technological change. It is important to emphasise that the NIS perspective does not conceptualise innovation as a discrete endeavour made by individual companies but rather as a combined effort of several parties including private and public institutions (Watkins, Papaioannou, Mugwagwa, & Kale, 2015). In this regard, the term national innovation capability is used which captures a nation's ability to coordinate resources and skills in such a way that present knowledge is converted into innovation (Fagerberg & Srholec, 2008; Lopez-Carlos & Mata, 2010). In line with Nelson (1988), Nelson and Winter (1982) and Freeman (1987) the present study assumes that this capability is an evolutionary learning process taking place within institutional structures. As a matter of fact, "effective learning requires institutional structures with appropriate legal institutions that develop human capital through appropriate education and research systems, build common infrastructures to enable knowledge sourcing and transfer, and facilitate business and market conditions to absorb, adopt and implement foreign advanced technologies" (Khedhaouria & Thurik, 2017, p. 49). Due to the fact that the NIS perspective especially highlights the importance of these conditions (Freeman, 1995; Lundvall, 1992; Lundvall et al., 2002) and, thus, broadens the view of endogenous growth theory, it is used as the underlying theory for the framework in this study. That is to say, the framework at hand considers innovation output as being determined by five conditions which are institutions, human capital and research, infrastructure, as well as market- and business conditions (Appendix A). Nowadays, exactly this five-pillar segmentation is used by the Global Innovation Index (GII, 2018) to consolidate the relevant spectrum of innovation drivers in its Innovation Input Sub Index. GII is a country ranking based on the assessment of a nations' innovation capacity and published annually by Cornell University, the European Institute of Business Administration (INSEAD) and the World Intellectual Property Organization (WIPO) (Dutta, Lanvin & Wunsch-Vincent, 2018). It assumes that the entire set of conditions should be improved in order for a country to strengthen its innovation capability.

2.2 Literature Review and Hypotheses

Diving deeper into the topic of the national innovation system, it becomes apparent that literature on NIS has revealed the emergence of several distinctive themes (Díaz-García, González-Moreno, & Sáez-Martínez, 2015). Since the 1990s, several performance-oriented studies have begun to examine the outcomes and results of inventive activity (Balzat & Hanusch, 2003). By contrast, another body of literature has tried to shed light on the drivers of innovation. In this respect, a rich and still growing body of literature has investigated innovation activity without a specific context whereas other authors have aimed at illustrating distinctive features in the context of a study. Analyses have been targeted at particular regions like Asian countries for instance (Hu & Mathews, 2005; Krammer, 2009). Likewise, researches have attempted to emphasise specificities when focusing on a particular type of innovation such as information and communication technologies (ICTs) (Lee, Nam, Lee & Son, 2016) to provide another example. Particularly noticeable is the fact that there are relatively few historical studies in the area of sustainability-related innovation (Klewitz & Hansen, 2013). Finally, the systemic approach has led a number of authors to bring into focus policy assessments and how the political framework can foster inventive activities of a country.

Even though the study is particularly interested in the drivers of green innovation, it is additionally going to concentrate on the body of literature covering antecedents of innovation in general. It is assumed that if certain factors have an influence on overall innovation activity of which eco-innovation is considered to be a sub-category, it follows that these factors impact eco-innovation in the same way. The reason for including a larger body of literature lies in the fact that research on determinants of eco-innovation is still in its infancy, and thus scarce. In this way, it is ensured that a broader spectrum of analysis approaches, useful methods, important outcomes and critical limitations are covered. It has to be pointed out, that literature on innovation drivers can be further classified into a micro-, meso-, and macro level (Díaz-García, González-Moreno, & Sáez-Martínez, 2015). Micro-level studies have paid attention to firm-specific influences on innovation, whereas meso-level research has predominantly considered the role of market dynamics. Macro-level studies have taken a more holistic and systemic view in that they trace results of interaction over a larger population. The thesis will particularly give attention to innovation determinants on macro-level. The unit of analysis is an entire nation which is subject to this study.

2.2.1 Institutions

As previously outlined, the NIS perspective originates from the neo-Schumpeterian theory of innovation which accentuates national inventive efforts to be particularly facilitated by institutions (Nelson & Winter, 1982). Formal institutions encompass policies, laws, constitutions, rights and regulations pertaining to a country’s regulatory-, business-, and political environment (Leftwich & Sen, 2010). They specifically stimulate innovation activity as they reduce uncertainty on the one hand and create incentives for companies on the other (Nelson, 2008). Considering a country's regulatory environment, the majority of research (Fu & Yang, 2009; Furman & Hayes 2004; Furman, Porter, & Stern, 2002; Krammer, 2009) indicates that a strong intellectual property rights (IPR) regime is a key predictor of innovation at the national level as it particularly provides incentives for participating in economic activities including innovation activities (Acemoglu, Johnson, & Robinson, 2005). More precisely, strong IPR policies incentivise domestic firms to invest in and develop patentable innovation on the one hand. On the other, they indirectly foster innovation activity by attracting inward foreign direct investment (FDI) with high spillovers (Fu & Yang, 2009; Krammer, 2009) as will be discussed in Section 2.2.5. Building on literature in national innovation systems, Furman, Porter, and Stern (2002) implement a novel framework, which is later applied by Furman and Hayes (2004) to understand national innovative capacity. Estimating a production function, both studies find that the strength of protection for intellectual property (IP) positively and significantly affects international patenting. Fu and Yang (2009) make use of a distinctive approach in order to analyse variances in patenting across countries by applying a stochastic frontier analysis. This standard efficiency estimation approach allows to analyse the efficiency of a country's innovation system and the drivers of that efficiency. Nonetheless, they similarly identify intellectual property rights protection to significantly and positively impact economic patenting efficiency. Focusing on Eastern European Transition Countries and bearing on a modified IPR index that combines two dimensions: legislative protection and the degree of enforcement, Krammer (2009) also finds that a strong IPR regime increases patenting. In contrast to previous findings, only Hu and Mathews (2005, 2008) do not detect evidence for a significantly positive relationship between IP protection and patent output. Adjusting the procedure of Furman, Porter, and Stern (2002) by applying it to five East-Asian countries (Hu & Mathews, 2005) and China (Hu & Mathews, 2008), they conclude that a strong IPR regime insignificantly and negatively affects patenting activity.

Exclusively focusing on intellectual property rights, the majority of authors mentioned earlier fail to consider other important dimensions of a nation's institutional framework as proposed by Dutta, Lanvin, and Wunsch-Vincent (2018). Indeed, convenient business conditions stimulate national inventiveness since designing favourable terms for starting as well as doing business fosters domestic entrepreneurship and attracts inventive activity of foreign companies (Krammer, 2009). Entrepreneurs demand innovation in the form of new products and new production methods in order to achieve competitiveness (Versakelis, 2006). Particularly, the reduction of time and effort for starting a business as well as the mitigation of administrative barriers encourage competitiveness and thus overall inventiveness of firms at the national level (Djankov, La Porta, Lopez-de-Silanes, & Shleifer, 2002; Lopez-Carlos & Mata, 2010). Whereas Ho and Wong (2007) take into account the number of procedures, days, and costs to start a business, as well as minimum capital required for registration, separately, Klapper, Laeven, and Rajan (2006) consolidate these factors into a composite index. Findings of both studies conform with each other in that they argue for a significant negative impact on the rate of entrepreneurship which in turn negatively affects national innovation output. Krammer (2009) reveals a direct effect on innovation measures and identifies the cost of starting a business to significantly decrease national patenting activity. In contrast, Thurik, Storey, and van Stel (2007) conclude that administrative aspects of starting a business including time, cost, procedures, seem to be unrelated to entrepreneurship rates across countries. Still, their results suggest that minimum capital requirements necessary for business start-up significantly lower business activities and hence inventive efforts.

Further, innovation is stimulated by a stable political environment as it mitigates uncertainty about doing business (Busenitz, Gomez, & Spencer, 2000; Khedhaouria & Thurik, 2017). Arguing in reverse, political instability provokes uncertainty and mistrust in the integrity of the political system and its actors. Uncertainty and mistrust prevent individuals from engaging in triple helix collaborations being cooperation between government, business and higher education as well as it inhibits foreign investment. Both aspects are crucial to foster the innovation system as pointed out by Allard, Martinez, and William (2012). As such, the authors conclude that political instability, measured as the likelihood that the government will be destabilised or overthrown by unconstitutional or violent means, has a statistically significant and negative effect on different measures of the national system of innovation including patenting intensity. Conversely, Waguespack, Birnir, and Schroeder (2005) find that political stability increases patenting activity, specifically investigating the effect of national political institutions in Latin America and the Caribbean. In the same vein, Versakelis (2006) identifies a statistically significant and positive effect of a nation's polity on innovation productivity.

As the majority of literature illustrates that a country's institutional framework allures business activities and entrepreneurship necessary for national innovation if it ensures intellectual property protection, business freedom and political stability, following hypotheses are formulated:

Hypothesis (1a): *The stronger intellectual property rights protection is, the higher environment-related patenting output.*

Hypothesis (1b): *The more favourable conditions for starting a business are, the higher environment-related patenting output.*

Hypothesis (1c): *The more stable the political environment of a country is, the higher environment-related patenting output.*

2.2.2 Human Capital & Research

In line with the NIS perspective, literature nowadays widely emphasises the importance of human capital and research development for innovation (Lee, Nam, Lee, & Son, 2016; Lin, 2014). This is because especially R&D institutions and education enhance knowledge creation which is in turn critical for innovation activity (Dutta, Lanvin, & Wunsch-Vincent, 2018; Khedhaouria & Thurik, 2017). In terms of R&D factors, previous literature (Fu & Yang, 2009; Furman & Hayes, 2004; Furman, Porter, & Stern, 2002; Hu & Mathews, 2005, 2008; Krammer, 2009; Shapiro, 2014; Versakelis, 2006) agrees that general R&D funding is a relevant determinant of national innovative capacity because it improves the quality of research institutions which in turn enhances the creation and assimilation of knowledge (Furman, Porter, & Stern, 2002). In that sense, Furman, Porter, and Stern (2002), Furman and Hayes (2004), Fu and Yang (2009), as well as Hu and Mathews (2005, 2008), find that national R&D expenditure proxied by expenditures in all sectors positively and significantly affects international patenting activity. Similarly, Versakelis (2006) supports these findings through a statistically significant coefficient of R&D expenditure intensity measured as the ratio of research and development expenditures, public and private, over GDP. Taking a more detailed view on R&D expenditures as a driver of national innovation, however, it becomes apparent that even though existing literature agrees on a significant influence of total expenditures on R&D, it provides contradicting results when splitting the indicator into public- and private R&D funding, respectively. This differentiation should be considered when analysing innovation drivers (Krammer, 2009) since it provides more profound insights into the effectivity of R&D funding sources. For example, Hu and Mathews (2005) emphasise a subtle, though important finding that distinguishes them from Furman, Porter, and Stern (2002), Furman and Hayes (2004), as well as from Fu and Yang (2009). They specifically find public R&D expenditure to significantly explain international patenting activity and deem this part to be more important than private R&D expenditures.

Literature on R&D funding by the private sector pertains to conditions of business sophistication and will be discussed in Section 2.2.5.

Apart from R&D considerations, literature within the NIS perspective points to educational factors having a substantial influence on national inventive activity (Fadul, 2014; Khedhaouria & Thurik, 2017; Lundvall, Johnson, Andersen, & Dalum, 2002). On the one hand, it is argued that skilled human capital including scientists is considered to be the output of the education production function while being an input of the knowledge production function. Hence, a sophisticated education system enables the development of highly skilled scientists and a well-trained workforce which in turn enhance knowledge creation (Versakelis, 2006). Education further facilitates the accumulation of a national pool of entrepreneurs who, in order to stay competitive, strive for innovation, new products and production processes. On the other hand, Furman, Porter, and Stern (2002) argue that the importance of education for innovation becomes manifest in sophisticated and quality-sensitive local customers. Customers are presumed to be more demanding for qualitative products and services if they are well-educated and demonstrate high cognitive abilities. However, little emphasis has been devoted to empirical testing of human capital development as a predictor of innovation (Versakelis, 2006). Delving deeper into the influence of public expenditures, contemporary literature (Furman & Hayes, 2004; Furman, Porter, & Stern, 2002) ascertains diverse results regarding public education expenditure. Furman, Porter, and Stern (2002), for instance, observe significant increases in patents dependent on public spending on secondary and tertiary education. This is in line with findings of Furman and Hayes (2004) who make use of the same variable operationalisations. In contrast, Hu and Mathews (2005), Krammer (2009) and Fu and Yang (2009) do not detect a statistically significant effect of higher education expenditure on the number of patents granted by the USPTO. In place of employing financial inputs of education production, Versakelis (2006) examines the effect of education quality, being the output of education production. He concludes that a higher quality of education measured by student's scores on internationally organised competitions has a positive impact on inventive activity. Additionally, Castellacci and Natera (2013) find that tertiary education as measured by tertiary enrolment ratio has a positive and significant effect on technological output proxied by the number of patents registered at the USPTO.

Furthermore, there seems to be broad agreement concerning the effect of aggregate employed science and technology personnel on countrywide innovation activity among existing research as this is crucial for knowledge production (Fu & Yang, 2009; Furman & Hayes, 2004; Furman, Porter, & Stern, 2002; Hu & Mathews, 2005, 2008; Lee, Nam, Lee, & Son, 2016; Maietta, 2015). That is, the number of patents granted by the USPTO, whether lagged by three years or not, is significantly and positively impacted by the number of full-time equivalent scientists and engineers in all sectors (FTE S&E) (Fu & Yang, 2009; Furman & Hayes, 2004; Furman, Porter, & Stern, 2002; Hu & Mathews, 2005, 2008). Similarly, Maietta (2015) concludes that the number of researchers positively impacts product innovation, applying a multi-probit regression. Particularly examining drivers of technological innovation in the ICT sector and applying fixed effects regression models, Lee, Nam, Lee, and Son (2016) also find a significantly positive impact of research personnel on national innovative activity.

Based on the foregoing discussion, showing that the majority of existing literature finds evidence for a significantly positive association between particular human capital factors and national innovation activity, the following hypothesis is posited:

Hypothesis (2)*: The higher* ***(a)*** *public R&D expenditure,* ***(b)*** *public education expenditure and* ***(c)*** *the number of research personnel is, the higher environment-related patenting output.*

2.2.3 Infrastructure

National inventive activity is further facilitated by a country's well-developed infrastructure (Dutta, Lanvin, & Wunsch-Vincent, 2018; Fagerberg & Srholec, 2008). While research in this field is not yet extensive (Khedhaouria & Thurik, 2017), existing studies specifically point to the importance of energy infrastructures (Castellaci & Natera, 2013) and communication infrastructures (Lee, Nam, Lee, & Son, 2016) for national innovation. The reason is that they enable the production and diffusion of knowledge essential for national innovation capability (Khedhaouria & Thurik, 2017). In this sense, Castellacci and Natera (2013), examining long-run relationships between general infrastructure measures and technological output, find that high levels of electricity consumption are significantly and positively associated with a large number of patents registered at the USPTO. Merely considering the general infrastructure dimension in terms of electricity output, however, their study makes no attempt to include other infrastructure conditions. Dutta, Lanvin & Wunsch-Vincent (2018) suggest information and communication technologies access to play a role in determining innovation performance. ICTs reduce the cost of accessing information and enable to diffuse it more widely through internet use (Fadul, 2014; Khedhaouria & Thurik, 2017; OECD, 2012). In this respect, Lee, Nam, Lee and Son (2016) detect a statistically significant impact of broadband network infrastructure measured by the number of broadband subscribers on the number of ICT patent grants.

Based on findings of existing literature, the following hypotheses are formulated:

Hypothesis (3a): *The greater electricity consumption is, the higher environment-related patenting output.*

Hypothesis (3b): *The better access to ICTs is, the higher environment-related patenting output.*

2.2.4 Market Sophistication

In keeping with the NIS perspective, a country's capability to innovate, further, depends on particular market conditions (Dutta, Lanvin, & Wunsch-Vincent, 2018; Khedhaouria & Thurik, 2017). That is, national market scale, access to international markets (Fagerberg & Srholec, 2008) and availability of financial resources to the private sector (Filipetti & Archibugi, 2011) are critical factors for companies to prosper and, thus, for national inventive activity to occur (Dutta, Lanvin, & Wunsch-Vincent, 2018). By measuring a nation's gross domestic product (GDP), many authors provide a useful variable operationalisation for market scale which is a valid indicator for economic and social health and measures a country's income level. Thereof, it is argued that high levels of GDP foster a country's innovation capability and maintain the production and commercialisation of innovation and technological accumulation (Castellacci & Natera, 2013). There is an explicit agreement among researchers with respect to a statistically significant and positive association between high levels of national GDP whether proxied by Gross Domestic product in billions of purchasing power parity (PPP)-adjusted 1985 (Furman, Porter, & Stern, 2002) –,1990 (Hu & Mathews, 2005) -, or 2000 US dollar (Furman & Hayes, 2004). Additionally, Furman and Hayes (2004) in accord with Hu and Mathews (2005), Fu and Yang (2009) and Castellacci and Natera (2013) discover a statistically significant and positive relationship between a country's income level as measured by GDP per Capita. Hu and Mathews (2008), though, find an insignificant association between GDP per Capita and the number of utility patents.

Moreover, literature highlights the fact that openness to international trade stimulates national inventive activity since it, firstly, enables technology transfers in the form of spillovers (Fagerberg & Srholec, 2008; Fu & Yang, 2009; Khedhaouria & Thurik, 2017). Secondly, it may intensify competition which forces domestic companies to innovate. Thirdly, market extension caused by exporting may result in incentives for innovation as returns on R&D investments can be increased (Fu & Yang, 2009). Furman, Porter, and Stern (2002) as well as Hu and Mathews (2005, 2008), both detect evidence for a significantly positive and economically relevant impact of openness to international trade and investment on national innovative capability. In the same vein, measuring openness to international trade by trade intensity, Castellacci and Natera (2013), Furman and Hayes (2004), and Krammer (2009) agree with authors mentioned above in that trade intensity positively affects patenting activity. Finally, Lee, Nam, Lee, & Son (2016), although only focusing on ICT goods exports, identify a statistically significant impact on ICT innovation in their one-year lag model. It is to mention, however, that there is no statistical significance identified with regard to their no-lag model.

Further, being part of market conditions, a robust financial system is essential for high levels of national innovation performance (Filippetti & Archibugi, 2011) as it ensures the availability of credit and with it required resources for firms to engage in innovation activities (O'Sullivan, 2005). It becomes apparent, though, that none of the aforementioned authors includes this aspect in their analyses. Girma, Gong, and Görg (2008) examine innovation activity in China and find that companies with good access to domestic bank loans exhibit a higher rate of inventive outcomes compared to firms having limited access.

Forgoing discussion reveals that the majority of literature finds evidence for a positive association between a country's innovation performance and market scale or international trade, respectively. Moreover, existing research suggests credit availability to have a positive impact on national innovation. Accordingly, the following hypotheses are formulated:

Hypothesis (4a)*: The larger the market scale of an economy is, the higher environment-related patenting output.*

***Hypothesis (4b)**: The more open an economy is to international trade, the higher environment-related patenting output.*

***Hypothesis (4c)**: The better the availability of credit to the private sector is, the higher environment-related patenting output.*

2.2.5 Business Sophistication

Dimensions of knowledge workers and the absorptive capacity of businesses pertain to the final condition that determines national inventive activity (Dutta, Lanvin, & Wunsch-Vincent, 2018; Khedhaouria & Thurik, 2017). Following Fu and Yang (2009) the importance of the private sector for innovation becomes manifest not only in financing and creating innovation ideas but also in the ability to commercialise them. As Section 2.2.2 proposes, human capital and research are decisive predictors of innovation. The knowledge worker dimension goes one step further as firms by themselves strengthen their innovation potential by employing and developing qualified personnel (Dutta, Lanvin, & Wunsch-Vincent, 2018). Indeed, literature agrees that business R&D funding facilitates the creation of knowledge workers which in turn is necessary for national innovation. In that sense, Hu and Mathews (2005) coincide with Furman, Porter and Stern (2002) when it comes to the proportion of private R&D expenditures in relation to total R&D expenditures. Both studies find R&D expenditures funded by industry over total R&D to enter positively and significantly. Similar outcomes are validated by Furman and Hayes (2004), Fu and Yang (2009) as well as Natario, Couto, Tiago and Braga (2011) who use cluster analysis and apply the European Innovation Scoreboard as a proxy for innovation activity in opposition to precedent research. Extending the work of Furman, Porter and Stern as well as of Hu and Mathews (2005), Hu and Mathews (2008) support those findings saying that private R&D funding positively and significantly influences innovation capability.

Considering the absorptive capacity of businesses, domestic innovation activity is stimulated by inward foreign direct investment (FDI) which is an investment in a domestic company by a foreign entity or individual with a lasting management interest of at least ten per cent in the form of mergers and acquisitions for instance. They enable the collection and diffusion of new knowledge through positive spillovers of the host country (Fu and Yang, 2009; Krammer, 2009). Aggregating inward FDI in globalisation factors, Krammer (2009) finds that FDI inflows have a significantly positive effect on patenting activity. Similarly, Girma, Gong, and Görg (2008) conclude that inward FDI at the sectoral level is positively associated with domestic innovative activity. Fu and Yang (2009), though, do not find a statistically significant impact of openness to FDI measured by the ratio of FDI to GDP on patenting.

As the majority of literature suggests national innovation activity to be positively impacted by private R&D funding and inward FDI, respectively, the following hypothesis is formulated:

Hypothesis (5)*: The higher* ***(a)*** *private R&D funding and* ***(b)*** *inward foreign direct investment is, the higher environment-related patenting output.*

3. Methodology

While preceding section provides an overview of the theoretical background and findings of existing research, this section aims at delivering insight into the empirical design chosen to answer previously developed hypotheses and, thus, the research question of what factors drive environmental-related innovation. For this reason, empirical models, sample, measures, as well as the analytical strategy are elucidated and justified.

3.1 Empirical Specification

Literature has formulated different models that try to assess certain effects on the determination of innovation activity. This study aims to consolidate the effects into a single and comprehensive framework based on five conditions as outlined above. Corresponding to the literature structure of the preceding section, the model of interest is developed. Due to the fact that the majority of previous literature has predominantly paid attention to institutional- as well as human capital conditions, appropriate factors conjointly build the base model. Subsequent models are specified, gradually incorporating factors on infrastructure-, market sophistication- and business sophistication conditions in order to explain the effect on environmental innovation output. Individual factors are chosen in accord with previously developed hypotheses and dependent on data availability. At the same time, the study accounts for a time lag between initial idea production and final reflection in patents which is in line with previous research (Fu & Yang, 2009; Hu & Mathews, 2005, 2008; Lee, Nam, Lee, & Son, 2016). As such, specifications are developed using 2-year lagged independent variables. Starting with institutional- as well as human capital and research factors, the study formulates Model (1) for country *i* at time *t* as follows:

$$lTPF-ENVTECH_{it} = \alpha + \beta_1 zIPR_{it-2} + \beta_2 zBusFree_{it-2} + \beta_3 zPolStab_{it-2} + \gamma_1 zPublRD_{it-2} + \gamma_2 zPersRD_{it-2} + \gamma_3 zEdShare_{it-2} + \varepsilon_{it} \quad (1)$$

where α and ε_{it} denote the individual effect for country *i* and the residual value, respectively. Environmental innovation output is proxied by $TPF-ENVTECH$ which is the dependent variable designating the number of Triadic Patent Families in selected environment-related technologies. In regard to the right-hand side of the equation intellectual property rights *IPR*, business freedom *BusFree*, and political stability *PolStab* represent institutions of a country's regulatory-, business-, and political environment, respectively. Factors of R&D financed by the public sector *PublRD*, aggregate research personnel *PersRD*, and expenditure on education *EdShare* conjointly cover human capital and research conditions. Model (1) serves as a base model and is augmented by factors of general infrastructure conditions next. Consolidating individual factors of Model (1) in vectors by using matrix notation, the study formulates Model (2) as follows:

$$lTPF-ENVTECH_{it} = \alpha + \beta' \, U^{INST}_{i,t-2} + \gamma' \, V^{HUM}_{i,t-2} + \delta_1 zGenInfr_{it-2} + \delta_2 zICTInfr_{it-2} + \varepsilon_{it} \quad (2)$$

where vector U^{INST} includes institutional factors *IPR*, *BusFree*, and *PolStab* and vector V^{HUM} incorporates *PublRD*, *PersRD*, and *EdShare*. General infrastructure *GenInfr* in terms of electricity consumption and broadband network infrastructure *ICTInfr* designate infrastructure conditions. Subsequently, Model (2) is expanded adding general market conditions. As such, the study formulates Model (3) as follows:

$$lTPF-ENVTECH_{it} = \alpha + \beta' \, U^{INST}_{i,t-2} + \gamma' \, V^{HUM}_{i,t-2} + \delta' \, W^{INFR}_{i,t-2} + \zeta_1 zGDPCap_{it-2} + \zeta_2 zOpenness_{it-2} + \zeta_3 zCredit_{it-2} + \varepsilon_{it} \quad (3)$$

where vector W^{INFR} encompasses *GenInfr* and *ICTInfr*. Infrastructure variables are followed by general market sophistication conditions including Gross Domestic Product per Capita *GDPCap,* openness to international trade $Openness$ and credit availability to the private sector, $Credit$. Finally, Model (3) is extended by incorporating factors regarding business sophistication conditions as well as an additional control variable resulting in Model (4) as follows:

$$lTPF-ENVTECH_{it} = \alpha + \beta' \, U^{INST}_{i,t-2} + \gamma' \, V^{HUM}_{i,t-2} + \delta' \, W^{INFR}_{i,t-2} + \zeta' \, X^{MARK}_{i,t-2} + \eta_2 zPrivRD_{it-2} + \eta_3 zFDI_{it-2} + \theta_1 zEdLevel_{it-2} + \varepsilon_{it} \quad (4)$$

where *GDPCap* and *Openness* are covered by vector X^{MARK}. Private R&D expenditure $PrivRD$ and inward foreign direct investments FDI constitute business sophistication conditions. In line with previous research, the analysis additionally controls for cross-country differences in educational level *Edlevel* as it is assumed to impact national productivity and efficiency of a country's absorptive capacity (Krammer, 2009). Specifically, higher education levels improve the productivity of innovation production (Engelbrecht, 2002; Krammer, 2009) which is the reason that *EdLevel* is expected to carry a positive sign. Expected signs of the remaining coefficients for Model (1) to (4) are derived from the discussion of the previous section and reported in Appendix G. Containing factors of all five innovation conditions, Model (4) is expected to explain more of the variation in Triadic Patent Families in selected environment-related technologies compared to previous models.

Due to the fact that the distribution of TPF-ENVTECH is positively skewed, the variable enters in logarithmic form for all models, normalising its distribution. This transformation handles the non-linear relation existing between response variable and regressors as the logarithm makes the effective relationship non-linear while preserving the linear model. Apart from controlling the skew, problems of heteroskedasticity and serial correlation are countered. Moreover, independent variables enter in standardised form for all models by subtracting the mean from each observation and dividing it by the standard deviation. This produces standardised regression coefficients or beta coefficients, respectively, having a mean of zero and standard deviation of one. Reason for this lies in the fact that independent variables are measured on different scales. With beta weights, the variables are put on a common scale counteracting potentially small coefficients approaching zero and thus aiding the interpretation of coefficients.

3.2 Data Description

In order to empirically investigate the effect of macro-level factors on national environmental innovation activity, the thesis refers to a fixed panel of 28 OECD countries concerned over the period 1998 to 2013. Table 1 lists all countries that have been incorporated into the analysis. Using secondary data, a longitudinal dataset is employed which is arranged in the long form (pooled dataset) and covers a total of 7168 observations. It is constructed from OECD Main Science and Technology Indicators (MSTI), World Bank comprising World Development - and World Governance Indicators, Heritage Foundation, and UN Human Development Reports. Appendix C provides definitions and sources for all variables under investigation. Pairwise correlations are reported in Appendix D. Descriptive statistics of employed variables including measures of central tendency (means), dispersion (standard deviations), minimum and maximum, as well as number of cases are reported in Appendix E. It becomes apparent that countries incorporated in the analysis hold on average 56 Triadic Patent Families in selected environment-related technologies. The highest number of environmental TPFs amounting to 745 can be attributed to Germany in the year 2001. Generally, the data reveals an upward trend of TPFs in environment-related technologies peaking in 2010 with a total of 2267 patent families. Until 2013, the number slightly drops to around 1800 TPFs. However, data reveals fluctuations in eco-innovation output for individual countries over time. The focus on OECD countries and the timespan up to and including the year 2013 are generally justified by data availability. Typically, data on potentially useful indicators tend to be more comprehensive for advanced- opposed to developing markets (Fagerberg & Srholec, 2008; Khedhaouria & Thurik, 2017). Correspondingly, the dataset contains 24 countries which are considered advanced-, and four countries deemed as being developing economies according to the International Monetary Fund's (IMF, 2018) World Economic Outlook Database. Eighteen countries are members of the European Union. Further, TPF data is particularly available up to and including 2013. Reason for that is an average five-year time lag between the priority date which is the first date of filing a patent application and the publication date at which information about the invention is disclosed to the general public (OECD, 2009). Still, not all data sources provide a complete set of observations for the countries and period of interest. On this account, datasets were matched employing linear interpolation- and extrapolation technique using Excel VBA trend analysis which results in a strongly balanced panel. In the following sub-sections, variables of interest are discussed elaborately.

Table 1: Sample Countries

Australia	Estonia	Iceland	Mexico	Spain
Austria	Finland	Ireland	Netherlands	Sweden
Belgium	France	Israel	Norway	Turkey
Canada	Germany	Italy	Poland	United Kingdom
Czech Republic	Greece	Korea (R.O.K.)	Portugal	
Denmark	Hungary	Luxembourg	Slovak Republic	

3.1.1 Dependent Variable

To proxy environmental innovation output, a variable is employed based on the number of Triadic Patent Families in selected environment-related technologies (TPF-ENVTECH). It is defined as a set of patents associated with environmental pollution, water scarcity, and climate change mitigation taken at the European Patent Office, Japan Patent Office, and United States Patent and Trademark Office that share one or more priorities (Dernis & Khan, 2004). The focus of the research is on visible commercialisable innovations as international patenting rates are generally deemed to be “the only observable manifestation of inventive activity with a well-grounded claim for universality” (Trajtenberg, 1990, p. 183). That is, in line with previous authors (Furman & Hayes, 2004; Furman, Porter, & Stern, 2002; Krammer, 2009), patents are the most expedient measure to compare innovative output across countries and over time. They are advantageous as data firstly is quantitative and, thus, generally applicable to statistical analyses.

Secondly, they are commensurable as patents rely on objective standards. Thirdly, patent data can be disaggregated into specific technology fields. Combined, these advantages form an appropriate basis for this research which aims at empirically testing environmental innovation output across countries.

However, patent counts are not exempt from limitations in providing internationally comparable indicators of technology performance. Firstly, there is no filter on patent's quality meaning that individual patents vary widely in commercial value. In fact, the value distribution within a single patent office is skewed as the number of low-value patents (having limited industrial application) exceeds the number of patents with substantial value (Dechezleprêtre, Ménière, & Mohnen, 2017; OECD, 2009; Popp, 2005). Secondly, a home advantage bias occurs when taking patent counts from individual patent offices (Criscuolo, 2006; Haščič, Silva, & Johnstone, 2015) because inventors usually file for protection in their home country first before filing at foreign patent offices. Specifically examining the USPTO and EPO, Criscuolo (2006) provides evidence for the effect: proportionate to their inventive activity, domestic applicants tend to file a larger quantity of patents with the PTO in their home country than foreign applicants do.

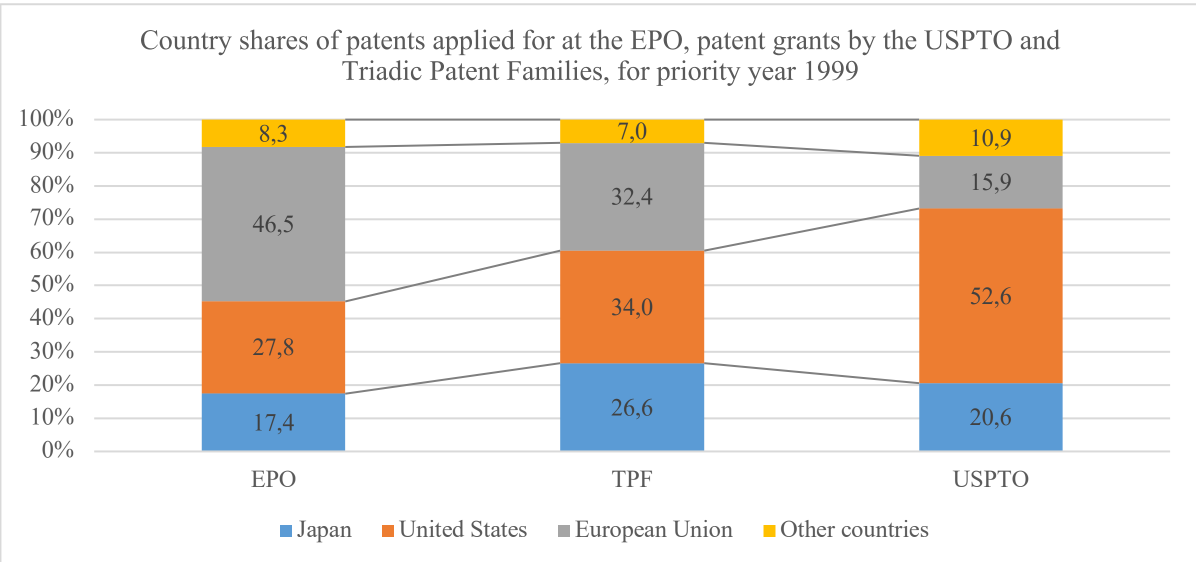

Figure 2. Country shares of patents applied for at the EPO, patent grants by the USPTO and Triadic Patent Families, for the year 1999. Adapted from "Triadic Patent Families Methodology," by H. Dernis and M. Khan, 2004, *Technology and Industry Working Papers,* OECD Publishing.

Figure 2 depicts this effect by providing country shares of patents applied for at the EPO, patent grants by the USPTO and Triadic Patent Families, for the year 1999. It can be seen that in 1999 the majority of countries (46,5%) applying for patents at the EPO are European countries. Similarly, the majority of patents the USPTO (52,6%) were granted to the United States in 1999.

Since historically published patent statistics typically refer to counts of patents applications to a single patent office, previous research tries to mitigate a potential home bias effect by omitting data from the analysis. In particular, past studies (Furman & Hayes 2004; Furman, Porter, & Stern, 2002; Krammer, 2009) predominantly use the number of patents granted by the USPTO but only to inventors from a particular country other than the U.S. as the dependent variable. This approach is not presumed to be the optimal solution since meaningful insights for identifying significant innovation drivers are not taken into consideration if data is omitted. Hence, this research refers to patent families which are sets of patents taken in various countries and protecting the same invention (Haščič & Migotto, 2015; OECD, 2009). Specifically, Triadic Patent Families are utilised incorporating patent filings in the Global Triad including Europe, Japan and the U.S. as outlined above. This way, a home advantage bias is resolved as shown by Criscuolo (2006) without causing data loss of specific countries and international comparability is eventually improved (Baudry & Dumont, 2006, p. 208). The application of TPF further mitigates the first limitation by facilitating data to be limited to more high-value patents than being present in patent counts from single PTOs (Criscuolo, 2006; Popp, 2005). The reason lies in the self-selection process. Indeed, additional expenses incur when filing patents at multiple patent offices, suggesting that inventors who are willing to bear those costs anticipate their patents to be of high practical value (Popp, 2005). Harhoff and Reitzig (2001) and Lanjouw and Schankerman (2001) provide evidence for patents generally being of higher value if they are member of families than those filed at a single PTO. Further, TPF data implicates the advantage that it can be disaggregated into specific technology fields which, in accord with the purpose of this thesis, allows to explicitly focus on patent data of selected environment related technologies. OECD search strategies for patent data of ENVTECH cover a total of 80 technological fields ranging from traditional environmental management domain such as air- and water pollution to mitigation of biodiversity threats and climate change (Popp, 2005). Fractional counts are used to allocate respective contributions of countries and avoid double counting if there are multiple inventors with different nationalities for the same patent (Dernis & Khan, 2004). That is, a patent co-invented, for instance, by one Dutchman and two Germans will be counted as 1/3 for the Netherlands and 2/3 for Germany. Hence, the dependent variable used becomes manifest in non-discrete (continuous) count data truncated at zero.

3.1.2 Independent Variables

The first set of explanatory variables pertains to a country's institutional framework. Both variables Intellectual Property Rights *IPR* and Business Freedom *BusFree,* conjointly covering the regulatory- and business environment, are extracted from Heritage Foundation. *IPR* measures the degree to which national laws protect intellectual property rights on the one hand and the extent to which government supervision enforces them on the other. *BusFree* measures the government's efficiency in regulating business activities. The indicator is based on ten factors regarding the difficulty of starting, operating, and closing a business. Scores of both variables are structured on a scale from 0 to 100, with higher numbers indicating higher certainty of legal protection and a larger extent of business freedom, respectively.

In view of the political environment, data on political stability, *PolStab*, captures the perceived probability of profound political disruptions and is retrieved from World Bank's World Governance Indicators. More precisely, the indicator is derived from a variety of surveys and aggregated into a standardised measure of a nation's overall political stability. It ranges from -2.5 to +2.5 with higher values indicating superior political stability. The second set of variables covers human capital and research conditions. The first two R&D related explanatory variables, *PublRD and PersRD* stem from OECD Science and Technology Indicators. Percentage of gross expenditure on R&D financed by the government is covered in Public R&D Expenditure, *PublRD*, and calculated by public expenditure in R&D divided by total R&D expenditures. Research personnel in R&D, *PersRD*, describes the number of researchers engages in R&D as per millions of people. Lastly, education expenditure, *EdShare*, is retrieved from World Bank. It encompasses government expenditure on education expressed as a percentage of GDP.

Similarly, infrastructure variables in terms of general infrastructure *GenInfr* and broadband network infrastructure *ICTInfr*, are gathered from World Bank Group. *GenInfr* constitutes a measure of electric power consumption produced by power plants and combined heat and power plants in kilowatt-hour divided by midyear population. *ICTInfr* measures the number of fixed broadband subscriptions to high-speed access to the public internet (TCP/IP connection).

Market sophistication predictors incorporate a measure of overall market scale. Following Furman and Hayes (2004), Hu and Mathews (2005), Fu and Yang (2009) and Castellacci and Natera (2013), market scale is measured by *GDPCap*, which becomes manifest in Gross Domestic Product per capita in PPP current international dollars in millions and extracted from World Bank's World Development Indicators. Openness to international trade, *Openness*, is measured by exports plus imports divided by GDP. Data is gathered from World Bank (WDI) which is also the case for credit availability, *Credit*. *Credit* is defined as financial resources provided to the private sector by financial corporations as a percentage of GDP.

Finally, business sophistication conditions become manifest in private R&D expenditures, *PrivRD*, and net inflows of foreign direct investments, *FDI*. Similar to *PublRD*, *PrivRD* stems from OECD MSTI and provides the percentage of GERD financed by the business enterprise sector. *FDI* net inflows in current US dollars are extracted from World Bank Group.

3.1.3 Control Variables

National education level, *EdLevel*, is proxied by mean years of schooling which is defined as the average number of years of education in the population aged 25 and older and gathered from United Nations' Human Development Reports. The variable is based on the widely used indicator of educational attainment level from Barro and Lee (2013).

3.3 Estimation Method

Having defined explanatory variables included in the models previously developed, the covariates are checked for multicollinearity using variance inflation factors (VIFs) in a next step. This is because high correlations suggest that two variables are measuring the same variance and will over-inflate R-squared. If so, only one variable is needed. VIF values of the particular independent variables range from 1.26 to 5.64 with a mean of 2.91 as reported in Appendix F. Applying commonly used threshold value of 10 for the VIFs (Burns & Burns, 2008, p.389) and a 0.8 benchmark for the strength of pair-wise correlation, results suggest no problems of multicollinearity. Hence, all explanatory variables are incorporated in the regression analysis.

The five models of interest are estimated using a simultaneous fixed effects regression conducted via StataSE 14. It is the nature of the underlying model that determines the appropriate regression type to be used. In particular, the results of the F-Test, Breusch and Pagan's (1980) Lagrange Multiplier (LM) Test and Hausman (1978) Test justify fixed effects regression for the longitudinal data as will be discussed in the following paragraph.

In the first instance, the existence of fixed effects is tested by the F-Test and based on loss of goodness-of-fit. The underlying null hypothesis predicates that all observed and unobserved fixed effects u_i are equal to zero. Results provide evidence that the null hypothesis can be rejected, suggesting that there is a significant fixed effect or a significant increase in goodness-of-fit in the fixed effect model. Consequently, a fixed effect model should be preferred over a pooled Ordinary Least Squares (POLS) model. Secondly, to examine the existence of random effects, Breusch and Pagan's Lagrange Multiplier (LM) Test is used. In this case, the null hypothesis states that individual or time specific variance elements are equal to zero. Results are suggestive of rejecting the null hypothesis and indicate that a significant random effect is present in the data. That is, a random effects model should be preferred over a pooled Ordinary Least Squares model since it allows for superior treatment of heterogeneity compared to POLS model. Thirdly, in order to investigate if a fixed- or random effects model is more appropriate for the analysis, the Hausman (1978) Test is employed which is based on the difference between the random- and fixed effects estimates. While the F-test denotes that at least one group or time specific intercept u_i is not equal to zero, it might be the case that these fixed effects are yet uncorrelated to the regressors (Hausman, 1978). The null hypothesis of the Hausman Test states that the difference in coefficients is not systematic in that there is no correlation between the unique errors and the explanatory variables. Results provide evidence of rejecting the null hypothesis meaning that the difference in coefficients is systematic. Hence, it can be reasoned that a fixed effects estimation serves as a more appropriate method than a random effects estimation for the analysis (Wooldridge, 2002, p. 288). Respective p-values of all three tests are reported in Table 2 together with the results of the estimation.

In order to ascertain that proposed estimates are efficient and standard errors are not biased, appropriate diagnostic tests are conducted. A modified Wald statistic which handles the violation of the normality assumption is calculated to test for group-wise heteroskedasticity in the idiosyncratic errors of the fixed effects regressions following Greene (2000, p. 598). Evidence is provided that the null hypothesis of homoskedasticity or homogeneity of variance, respectively, can be rejected for all models. Causing bias in the standard errors, the absence of homoskedasticity can invalidate statistical significance tests (Hoehn, Schuberth, & Steiner, 2014). Even though not necessarily problematic in the panel at hand which can be defined as a micro panel covering a short time period under 20 years, serially correlated idiosyncratic errors may further cause standard errors of the fixed effects estimators to be understated and higher R-square as shown by Bertrand, Duflo, and Mullainathan (2004). To examine serial correlation in the residuals, a test proposed by Wooldridge (2002, p. 274) is employed. Results give evidence that the null hypothesis of no first-order autocorrelation cannot be rejected for all models. Further, as the panel is characterized by small T and large N, a postestimation test described by Pesaran (2015) is employed to test residuals for weak cross-sectional dependence. The underlying null hypothesis stating that residuals are weakly cross-sectional dependent can be rejected for all models. Even though serial correlation seems not to be a problem, cluster robust covariance estimators treating each country as cluster are used to correct for heteroskedasticity as proposed by Wooldridge (2013, p. 483). Diagnostic test results are reported in Table 2.

4. Results

Having justified the choice of the empirical estimation, results of the fixed effects regressions using cluster robust estimators will be discussed in this section. The respective results of Model (1), (2), (3), and (4), are reported in Table 2.

4.1 Main Empirical Results

As previously indicated, the study aims to provide a comprehensive framework in terms of innovation dimensions as proposed by theory of the national innovation system perspective. The majority of previous literature has predominantly brought into focus institutional- and human capital conditions to empirically explain innovation activity. In order to determine whether the addition of factors relating to infrastructure-, market sophistication- as well as business sophistication conditions provides an improvement in predicting environmental-related innovation activity, individual independent variables enter cumulatively in the regression using Model (2), (3), and (4).

Investigating the estimation results in consideration of R-squared, the development of Model (4) being derived from preceding models unveils a considerable improvement of general fit. As conditioned by the properties of the fixed effects estimation it is the R-squared within level which is an ordinary R-squared and of main interest in the light of the study's research problem. Being more precise, the study aims to elucidate factors causing time series variation within individual countries. Accordingly, R-squared within describes the explanatory power of the independent variables after partialling out the fixed effects. Model (1) produces a within R^2 = 9.4% which is significantly different from zero (F = 4.57, p = 0.003) suggesting that the model accounts for approximately 9.4 per cent of total variance within the panel units. Adding infrastructural factors, Model (2) generates a within R^2 = 10.6% again being significantly different from zero (F = 4.23, p = 0.002.). Individual factor importance of each condition can be assessed by comparing values of within R-squared with the particular forgoing estimation that does not include these factors. In this way, contrasting Model (2) with Model (1), R-squared within raises by 0.012, suggesting that infrastructure measures account for approximately 11.3 per cent of within variation in Model (2). Model (3) produces a within R^2 = 15.5% which is significantly different from zero (F = 5.42, p = 0.000). Similarly, opposing Model (3) to Model (2), within

R-squared is increased by 0.049, providing evidence that market sophistication indicators account for roughly 31.6 per cent of within variation in Model (3). Model (4) finally produces a within R^2 = 17.4% which is significantly different from zero (F = 4.87, p = 0.000). Comparing Model (4) with Model (3), within R-squared is increased by 0.019 when business condition factors, as well as the control variable, are incorporated, indicating that they account for approximately 10.9 per cent of variation within countries in Model (4).

In summary, results of R-squared within suggest more variation in Triadic Patent Families of environment-related technologies within countries to be explained by the amplified model. That is, incorporating indicators of all five innovation conditions, Model (4) outperforms preceding models in terms of general fit. Further satisfying the aim of this research to provide a comprehensive framework, it is the preferred model. For this reason, conclusions are ultimately drawn from results of Model (4) which will be discussed elaborately in the following paragraphs.

Referring to Table 2, Model (4), reveals diverse results in terms of factor importance compared to previously stated expectations. Considering anticipated significance and direction of relationships between predictor variables and TPF-ENVTECH, results substantiate expectations to some extent. Simultaneously, the analysis discloses results that have not been expected beforehand. Beginning with institutional conditions, Hypothesis (1a) suggests that the stronger a country's intellectual property rights protection is, the higher environment-related patenting output. No evidence is found that intellectual property rights exert a statistically significant effect on Triadic Patent Families in selected environment-related technologies (β_1 = -.134, p = .393). Thus, using a .05 significance level, Hypothesis (1a) is rejected. Hypothesis (1b) suggests that the more favourable conditions for starting a business are, the higher environment-related patenting output. It is found that business freedom does not seem to be significantly associated

Table 2: Estimation lTPF-ENVTECH using Model (1), (2), (3), and (4)

Independent Variable	Model (1)	Model (2)	Model (3)	Model (4)
zIPR	-0.227	-0.195	-0.156	-0.134
	(0.206)	(0.191)	(0.166)	(0.154)
zBusFeee	-0.011	-0.085	-0.083	-0.120
	(0.049)	(0.082)	(0.079)	(0.082)
zPolStab	-0.029	0.023	0.048	0.080
	(0.188)	(0.196)	(0.194)	(0.187)
zPublRD	0.152	0.125	0.056	0.122
	(0.184)	(0.194)	(0.175)	(0.144)
zPersRD	0.450	0.168	0.143	0.107
	(0.138)	(0.189)	(0.181)	(0.205)
zEdShare	0.350**	0.326**	0.283*	0.281**
	(0.145)	(0.148)	(0.139)	(0.131)
zGenInfr	-	0.044	0.005	-0.045
		(0.166)	(0.135)	(0.109)
zICTInfr	-	0.170	-0.112	-0.137
		(0.127)	(0.180)	(0.194)
zGDPCap	-	-	0.501	0.452
			(0.373)	(0.365)
zOpenness	-	-	-0.215	-0.341
			(0.321)	(0.347)
zCredit	-	-	0.339**	0.339*
			(0.151)	(0.167)
zPrivRD	-	-	-	0.164
				(0.112)
zFDI	-	-	-	0.033*
				(0.018)
zEdLevel	-	-	-	0.295*
				(0.157)
Constant	2.581***	2.576***	2.528***	2.517***
	(0.022)	(0.023)	(0.031)	(0.030.)
N (observations)	354	354	354	354
N (groups)	28	28	28	28
R^2: (within)	0.094	0.106	0.155	0.174
(between)	0.002	0.001	0.183	0.319
(overall)	0.024	0.011	0.205	0.331
F-Test (p-value)	0.003	0.002	0.000	0.000
LM-Test (p-value)	0.000	0.000	0.000	0.000
Hausman Test (p-value)	0.044	0.004	0.008	0.000
Wald: H0 homoskedast.	12305.87***	8975.25***	11439.30***	14181.10***
Wooldr: H0 no serial corr.	1.226	1.232	1.375	1.340
Pesar: H0 cross-sect. dep.	7.045***	8.220***	5.904***	3.777***

Fixed effects estimation of models (1), (2), (3), and (4). A balanced panel of 28 countries covering the period from 1998 to 2013 is used. Standard errors (robust to heteroscedasticity) are in parentheses.
(Two-tailed) significance levels: *10%; **5%; ***1%

with Triadic Patent Families in selected environment-related technologies (β_2 = -.120, p = .155). Hence, using a .05 significance level, Hypothesis (1b) is rejected. Hypothesis (1c) suggests that the more stable the political environment of a country is, the higher environment-related patenting output. No evidence is found for a statistically significant relationship between political stability and Triadic Patent Families in selected environment-related technologies (β_3 = .080, p = .673). Thus, using a .05 significance level, Hypothesis 1c is rejected.

Turning the experimental evidence on human capital and research related variables, Hypothesis (2) suggests that the higher (a) public R&D expenditure, (b) public education expenditure and (c) the number of research personnel is, the higher environment-related patenting output. Results neither reveal evidence for a significant relationship between public R&D spending and TPF-ENVTECH (γ_1 = .122, p = .405), nor between the number of researchers and TPF-ENVTECH (γ_2 = .107, p = .607). However, evidence is found that governmental expenditure on education significantly predicts Triadic Patent Families in selected environment-related technologies (γ_3 = .281, p = .041). Particularly, the coefficient implies that a one unit increase in the standardised variable (*zEdShare*) or a 1.24 percentage point increase in *EdShare*, respectively, is associated with an approximately 32.4 per cent increase in TPF-ENVTECH. Consequently, using a .05 significance level, Hypothesis (2) is partially supported.

In terms of infrastructure variables, Hypothesis (3a) suggests that the greater electricity consumption is, the higher environment-related patenting output while Hypothesis (3b) proposes that the better access to ICTs is, the higher environment-related patenting output. No evidence is found that either electricity consumption (δ_1 = -.045, p = .683) or the number of broadband subscriptions (δ_2 = -.137, p = .488) exerts a statistically significant effect on Triadic Patent Families in selected environment-related technologies. For this reason, using a .05 significance level, Hypothesis (3a) and (3b) are both rejected.

Shifting the focus to variables of market sophistication conditions, Hypothesis (4a) suggests that the larger the market scale of an economy is, the higher environment-related patenting output. It is found that GDP per Capita does not seem to be significantly associated with Triadic Patent Families in selected environment-related technologies (ζ_1 = -.452, p = .226). Thus, using a .05 significance level, Hypothesis (4a) is rejected. Hypothesis (4b) suggests that more open an economy is to international trade, the higher environment-related patenting output. It is found that trade openness does not seem to exert a statistically significant effect on TPF-ENVTECH (ζ_2 = -.341, p = .335). Again, using a .05 significance level, Hypothesis (4b) is rejected. Hypothesis (4c) suggests that better the availability of credit to the private sector is, the higher environment-related patenting output. Evidence is provided that credit availability significantly contributes to the prediction of environmental innovation activity, namely, Triadic Patent Families in selected environment-related technologies (ζ_3 = .339, p = .052). Consequently, it can be inferred that if the standardised variable (*zCredit*) is increased by one unit or *Credit* is increased by 45.863 percentage points, respectively, Triadic Patent Families of environment-related technologies are expected to increase by approximately 40.4 per cent. Thus, using a .10 significance level, Hypothesis (4c) is supported.

Considering business sophistication conditions, Hypothesis (5) suggests that the higher (a) private R&D funding and (b) inward foreign direct investment is, the higher environment-related patenting output. No evidence is found for private R&D funding to be significantly related to TPF-ENVTECH (η_1 = .164, p = .156). However, evidence is provided that inward foreign direct investments exert a statistically significant effect on Triadic Patent Families in selected environment-related technologies (η_2 = .033, p = .074). Particularly, it can be reasoned from the coefficient that by increasing the standardised variable (*zFDI*) by one unit which is an increase of 57848.42 million US dollars in *FDI*, is associated with an increase in TPF-ENVTECH of approximately 3.4 per cent. Thus, using a .10 significance level, Hypothesis (5) is partially supported. Finally, evidence is provided that a nation's education level, which enters as a control variable in the regression, is significantly associated with the number of Triadic Patent Families in selected environment-related technologies (θ_1 = .295, p = .071). The coefficient indicates that by increasing the standardised variable (*zEdLevel*) by one unit or *EdLevel* by 1,764 years, respectively, TPF-ENVTECH is expected to increase by roughly 29.5 per cent.

In summary, these results suggest institutional- as well as infrastructural conditions to have less of an effect on environmental innovation output. However, human capital and research-, market sophistication- as well as business sophistication conditions seem to play a role in explaining the within-country variation in the number of Triadic Patent Families in selected environment-related technologies. A list of formulated hypotheses including expected signs and respective findings are reported in Appendix G.

4.2 Robustness Checks

For the purpose of providing evidence of structural validity from coefficient robustness, additional robustness checks are performed. That is, following Lu and White (2014), coefficient estimates are being assessed by modifying the benchmark model, Model (4).

As existing research does not agree on a definite time lag between initial idea production and final reflection in patents, a first robustness check, Robust (1), takes into account all covariates with a one-year time lag (t-1). By this means, coefficients are checked for variation dependent on a shorter time-lag assumed between idea production and patenting output. That is, regressors predict TPF-ENVTECH one year earlier compared to Model (4). Secondly, Robust (2) investigates if the benchmark model is robust to the reduction in sample size. With the intention of increasing relative weight of developing countries in the analysis, the sample is specifically reduced by two countries, Portugal and Sweden, which are considered advanced economies according to IMF's (2018) World Economic Outlook Database. Moreover, existing research applies different variable operationalisations for human capital in Research and Development. Following Fu and Yang (2009) and Maietta (2015), Model (4) incorporates *PersRD* specifically measuring the number of researchers as per millions of people. In line with Lee, Nam, Lee and Son (2016), Robust (3) replaces *PersRD* with *FTERD* measuring total R&D personnel per thousand labour force. In this manner, it is investigated if a broader definition of human capital in R&D which, apart from researchers, includes general research personnel, causes changes in results. Finally, Robust (4) includes an additional regressor to the estimation. Krammer (2009) proposes that market scale as proxied by population size may affect innovation output as countries with higher population are expected to produce more innovation output. Hence, *Popul*, measuring the size of the population is included.

Results of the four robustness tests are summarised in Appendix H. Generally, they are consistent with those results of the benchmark model. Having made modifications in the form of shifting the time lag between regressors and regressand, reducing sample size, swapping variables, and increasing the number of covariates, results provide evidence for structural validity of Model (4). Nevertheless, minor deviations become apparent on closer inspection. Predominantly, they manifest themselves in coefficients generating opposing signs when shifting the time lag from two years to one year in Robust (1). That is, the coefficient of *IPR* changes from negative to positive while public R&D coefficient changes from positive to negative compared to Model (4). Still, Robust (1) reports insignificance for both coefficients using a .10 significance level which is again in line with the benchmark model. Moreover, significance levels vary slightly when altering the time lag or reducing sample size. The coefficient of *EdShare*, for instance, becomes strongly significant at the .01 level in Robust (1). Similarly, coefficients of Credit increase their significance level to the 0.5 level in Robust (1) and (2) in the same way as FDI coefficient does in Robust (2).

Finally, it may be concluded that coefficients reveal qualitative equivalent results after employing specific modifications. Notwithstanding that isolated coefficients vary slightly in significance levels, results seem to be reliable and provide evidence for structural validity of the preferred model, Model (4).

5. Discussion

A meaningful body of literature emphasises the importance of general national innovation activity for a country's economic performance. Similarly, environmental innovation can enhance economic development. While the management of climate change and development of related technologies and services has transformed into a growing industry with new market opportunities (OECD, 2011), literature specifically examining drivers of eco-innovation seems to be still in its infancy (Díaz-García, González-Moreno, & Sáez-Martínez, 2015; Klewitz & Hansen, 2013). Additionally, existing research appears to be rather fragmented concerning coverage of relevant dimensions of innovation drivers and consequently does not provide a holistic framework of key factors as outlined by Khedhaouria & Thurik (2017). This study contributes to empirical literature by examining drivers of environmental innovation at national level for 28 OECD countries and by aggregating different strands of literature into a comprehensive framework to provide a more holistic perspective. The analysis is based on theoretical grounds of the national innovation system which identifies institutional-, human capital and research-, infrastructural-, market sophistication-, and business sophistication conditions to build key dimensions impacting innovation activity. Moreover, Triadic Patent Families are employed as a proxy for innovation output to solve some of the limitations caused when using patent counts of a single patent office, thereby improving international comparability. Results are robust to employed estimation technique and eventually reveal several interesting observations.

5.1 General Discussion

Generally, the analysis evinces institutional- as well as infrastructural conditions to have less of an influence on innovation activity associated with environmental technologies. However, individual factors within the scope of human capital and research-, market sophistication- as well as business sophistication conditions are found to play a role in determining the number of Triadic Patent Families in selected environment-related technologies. Subsequently, results of individual determinants of aforementioned conditions are discussed individually.

Beginning with institutional conditions, the analysis has been unable to provide evidence for institutional factors of a country's regulatory-, political-, and business environment (U^{INST}), respectively, to be significantly associated with variations in the rate of environment-related patenting. This is surprising since the role of institutions in facilitating inventive efforts is deeply embedded in the neo-Schumpeterian theory of innovation and, thus, in the definition of the national innovation system perspective. For this reason, it was specifically hypothesized that strong intellectual property rights protection leads to higher environment-related patenting output. In contrast to Fu and Yang (2009), Furman and Hayes (2004), Furman, Porter, and Stern (2002), and Krammer (2009), who conclude that the strength of a country's intellectual property rights regime is significantly associated with general patenting, the study suggests IPR systems to have less of an effect on environment-related innovation. In line with Hu and Mathews (2005, 2008), results reveal that IPR seems to be insignificant when explaining variances in Triadic Patent Families in selected environment-related technologies while a slight negative effect was detected. On the one hand, insignificance might be explained by the fact that IPRs are assumed to be a consequence of innovation rather than a cause (Boldrin & Levine, 2010). On the other hand, Boldrin and Levine (2010) refer to the term "intellectual monopoly" in order to explain why a robust IP system may hinder innovative progress in developing countries' domestic industry. Defined as the ability of inventors to control product usage, intellectual monopoly hinders competition and thus decelerates the speed of further technological development in the technological field of the invention being secured. This might explain a negative sign although no statistical significance was detected implying that the study is incapable of drawing concrete conclusions regarding the effect of IPR protection strength. Apart from a strong IPR regime, the study hypothesised that favourable conditions for starting and doing business are conducive to eco-innovation activities. No evidence is found, that a government's efficiency in regulating business activities which includes facilitating the ease of starting and operating a business is related to environmental patenting. In agreement with Thurik, Storey, and van Stel (2007) this result is likely to be associated with administrative considerations of starting a business being unrelated to the formation rate of businesses because creative entrepreneurs handle bureaucratic burdens. There are, however, other possible explanations. Similarly, the analysis has been unable to demonstrate a hypothesised significant effect of a country's political stability on environmental-related patenting output contrary to conclusions reached by Allard, Martinez, and William (2012), Versakelis (2006) and Waguespack, Birnir, and Schroeder (2005).

Nevertheless, results of the analysis indicate human capital and research conditions (V^{HUM}) to play a role in determining eco-innovation output. It was hypothesised that an increase in public R&D- and public education expenditure, as well as in the number of research personnel, is associated with higher environment-related patenting output. It should be noted that previous studies especially evaluating the influence of public education expenditure on national innovation capability observe inconsistent results. This study corroborates the findings of Furman and Hayes (2004), Furman, Porter, and Stern (2002), and Versakelis (2006) by providing evidence for governmental education expenditure to positively impact environment-related inventive activity measured by TPF-ENVTECH. Additionally, it should be acknowledged that the coefficient does not only enter in a statistically significant- but also in an economically significant manner suggesting that increasing the share of GDP spent on education by 1.24 per cent is associated with an increase of approximately 32.4 per cent in Triadic Patent Families in selected environment-related technologies. One possible explanation emerging from previous literature is that investment in a sophisticated education system facilitates the development of a well-trained workforce and highly skilled scientists who in turn are essential input factors for knowledge creation and thus inventive activity. Following this reasoning, it should be expected that research personnel exert a positive impact on inventive activity correspondingly. However, neither does the thesis detect evidence for a significant increase in Triadic Patent Families associated with the number of R&D personnel in general nor with the number of researchers in particular (Robust 3). Firstly, this result is inconsistent with findings of Fu and Yang (2009), Furman and Hayes (2004), Furman, Porter, and Stern (2002), Hu and Mathews (2008), as well as with Maietta (2015) who consider R&D personnel to be a relevant factor explaining innovation. Secondly, it contests previously stated explanation. Rather, findings mentioned above conjointly substantiate explanations provided by Furman, Porter, and Stern (2002) as well as Versakelis (2006) arguing that the importance of education is best understood from a demand- rather than a supply-side perspective. On the one hand, sophisticated and quality-sensitive local customers play a role in that they might be more environmentally conscious if they are well-educated which leads them to not only demand high-quality products but also environment-related technologies. On the other hand, education facilitates developing a national pool of entrepreneurs who in turn demand environmental innovation in order to achieve competitiveness. This reasoning might further hold for the economically relevant finding of a nation's level of education in terms of years of schooling to significantly and positively being associated with environmental innovation activity. The results indicate that by increasing mean years of schooling by 1.76 years, the number of Triadic Patent Families in selected environment-related technologies is expected to rise by approximately 29.5 per cent. Apart from these findings, the study is not able to discover a significant impact of R&D expenditures by the public sector on Triadic

Patent Families implying that no concrete conclusions can be drawn in this regard. This is contrary to findings of Hu and Mathews (2005) who find a significantly positive relationship. However, it should be noticed that other authors have not explicitly examined the effect of governmental R&D funding on national innovation activity.

Similarly, very little was found in the literature on the question if electric infrastructure and ICT infrastructure conditions (W^{INFR}) affect patenting efficiency. The study hypothesised that higher environment-related patenting output is associated with greater electricity consumption and better access to ICTs, respectively. However, results of existing research (Castellacci & Natera, 2013; Lee, Nam, Lee, & Son, 2016) are not supported as no evidence is found neither for general electricity consumption nor for broadband network subscriptions to be significantly associated with innovation activity. Even though a common infrastructure is generally said to facilitate knowledge transfer and diffusion following the view of the NIS perspective, it seems possible that well-established broadband infrastructures is rather important for knowledge-based innovation with regard to information and communication technologies. Cloud computing, for instance, which operates over a broadband network is a crucial platform for innovative services (Lee, Nam, Lee, & Son, 2016). However, data must be interpreted with caution as other possible explanations may exist.

Shifting the focus to market sophistication conditions (X^{MARK}), better availability of credit to the private sector was presumed to lead to higher environment-related inventive activity. In fact, the analysis has revealed a significant effect of the amount of credit provided to the business sector on national environmental-related patenting output. This result corroborates findings of Girma, Gong, and Görg (2008) and suggests that an efficient financial system ensuring the availability of credit significantly affects patenting activity related to green technologies. Intuitively, it makes sense that financial resources play a pivotal role for firms to engage in innovation activities which is widely acknowledged by previous literature (D'Este, Iammarino, Savona, & von Tunzelmann, 2012; Hölzl & Janger, 2012; O'Sullivan, 2005). It can be argued that the amount of credit provided covers the robustness of the financial sector and, further, accounts for the extent to which collateral and bankruptcy laws nurture lending by preserving the rights of lenders and borrowers (O'Sullivan, 2005). This seems to be important also for patenting activity of environment-related technologies. Moreover, it was hypothesised that an increase in environment-related patenting is associated with larger market scale and an economy more open to international trade, respectively. In line with Hu and Mathews (2008), no evidence for a significant relationship has been found between general market scale as measured by GDP per Capita and eco-innovation output. However, this finding is contrary to findings of Castellacci and Natera (2013), Fu and Yang (2009), Furman and Hayes (2004), and Hu and Mathews (2005) who conclude that GDP per Capita has a statistically significant and positive effect on national innovation activity. Similarly, the study is not able to detect a significant influence of a nation's openness to international trade on environment-related innovation activity which stands in contrast to findings of Castellacci and Natera (2013), Furman and Hayes (2004), Furman, Porter, and Stern (2002), Hu and Mathews (2005, 2008), Krammer (2009), as well as Lee, Nam, Lee and Son (2016). Literature within the NIS perspective argues that openness to trade facilitates innovation activity because it creates knowledge externalities. In particular, imports allow for additional knowledge absorption. Further, it is argued that international trade opens up new markets increasing the demand side. In particular, exports enable increased market access and thus the possibility to appropriate more rents. As these explanations refer to imports and exports, separately, one justification for insignificance in the trade openness variable might be that these effects cannot be disentangled by the measuring imports and exports in a single factor. Having a closer look at previous research, Lee, Nam, Lee, and Son (2016) find evidence for trade openness being significantly and positively related to ICT innovation in their 1-year- and 2-year time lag model by proxying openness with ICT exports. Furman, Porter, and Stern (2002), Hu and Mathews (2005), further, find a significantly positive effect on national innovation output making use of an average survey response by executives regarding relative openness of economy to international trade and investment from IMD world competitiveness report.

Finally, business sophistication conditions seem to exert influence on environment-related innovation. It was hypothesised that higher private R&D funding as well as foreign direct investment, respectively, is associated with a higher number of environment-related patenting output. Findings especially supplement previous evidence provided by Girma, Gong, and Görg (2008) and Krammer (2009) suggesting that inward foreign direct investments positively and significantly impact Triadic Patent Families in environment-related technologies. This result is likely to be related to positive externalities in the form of technology transfers. That is, inward FDI may enable the host country to collect and disseminate knowledge which in turn facilitates innovation. With relatively low coefficient, inward foreign direct investments seem to play a statistically important, though, economically subtle role for environmental-related innovation activity. Although there is broad agreement among existing literature concerning the importance of R&D funding by the private sector for national innovation capability, surprisingly, the thesis is not able to support previous research (Fu & Yang, 2009; Furman & Hayes, 2004; Furman, Porter, & Stern, 2002; Hu & Mathews, 2005, 2008; Natario, Couto, Tiago, & Braga, 2011) as no evidence is found for a significant relationship between private R&D and Triadic Patent Families in selected environment-related technologies.

5.2 Political Implications

As suggested at the beginning of the paper, this research aims at providing an empirical model for governments a well as for international organisations to better comprehend environment-related innovation drivers. Generally, results of the analysis indicate that public policy has an effect on a country's national innovative activity. It follows that a variety of policy implications can be derived that intend to enhance national innovation performance and, thus, productivity and competitiveness of economies.

Firstly, results suggest that governmental expenditures on education facilitate environment-related innovation activity arguing from a demand-side perspective. It is reasoned that well-educated people being more aware of environmental conditions and their impacts tend to demand more environmentally friendly technologies. In the same vein, education may augment the national pool of entrepreneurs who are in turn demanding eco-innovation to gain competitiveness. In fact, uncertainty about market demand is one of the principal barriers to a rapid upswing of environment-related technologies according to the OECD (2011). It follows that apart from mobilising additional education funding, political strategies should possibly focus more strictly on stimulating the demand for eco-innovation through promotion and education to achieve greater acceptance of environment-related technologies and processes. Efforts from local, regional, national as well as supranational authorities might need to step up in conjunction in order to successfully obtain acceptance. Particularly, communication activities need to be implemented elucidating the significance of eco-innovation for the environment on the one hand, and for a sustainable economy creating new workplaces and generating economic wealth on the other. By this means stronger and more stable demand for environmental innovation can be achieved.

Secondly, the study provides evidence that robustness of a country's financial system in terms of good and stable access to credit for the private sector nurtures eco-innovation efforts. In this case, it can be argued from both a demand- as well as from a supply side perspective. On the one hand, access to finance might enable the development and commercialisation of environmental technologies. On the other hand, it, in turn, might encourage entrepreneurial activities demanding these technologies. In fact, relative immaturity of the market still causes difficulties in terms of access to finance for companies being involved in eco-innovation as commercial risk is high (Grandinetti, 2016; OECD, 2011). Especially, if there is an absence of collateral or an insufficient track record, nascent companies either receive loans on less favourable terms or face difficulties even to obtain external financing from banks and, thus, in engaging in innovation activities. Effective eco-innovation policies in the form of sophisticated financial instruments can lay the foundation to facilitate the flow of capital for innovative entrepreneurs. Additionally, these can be individually tailored to support those entrepreneurs and companies that participate in activities related to environmental technologies. Financial instruments that provide guarantees, for instance, counteract a lack of creditworthiness as the government assumes a company's debt obligation in case the firm defaults. This way risk for the bank is mitigated finally encouraging banks to either grant loans at all or at better conditions to companies engaging in eco-innovation.

Thirdly, taking into consideration business sophistication conditions, evidence is provided that inward foreign direct investments foster national environment-related innovation, albeit in a conservative manner. It is argued that inward FDI allows for resource transfers including knowledge spillovers which provide countries access to new environmental technologies. Politics may attract foreign corporate presence and explicitly stimulate and coordinate resulting transfers through special tax instruments using a targeted strategy (OECD, 2003). As a general reduction of the statutory corporate tax rate attracts a broad range of industries, a selective approach in terms of tax incentive schemes may be more efficient to specifically lure environment-related companies. Investigating the case of FDI in renewable energy (RE) technologies, Wall, Grafakos, Gianoli, and Stavropoulos (2018), provide evidence that especially fiscal measures such as tax incentives are one of the most significant policy instruments facilitating FDI in the RE sector. Tax incentives are further advantageous for nations by reason of an easier and more cost-efficient implementation compared to a general reform of the tax system (Morisset & Pirnia, 2000). As such tax holidays or temporary rebates, being a special form of tax incentives, constitute a valuable instrument to lower the corporate income tax rate and can particularly relieve foreign companies engaging in eco-innovation activities. Tax holidays are further beneficial in that companies can draw more considerable benefits the more profitable they are, thus, being particularly incentivised. Because tax holidays tend to remunerate the launch of new- rather than investments in existing companies, tax allowances are a special instrument to achieve the latter. By allowing to deduct a percentage from taxable income these can similarly encourage capital investment in environmental technologies.

It can be concluded that it is a combination of supply- and demand side approaches politics should pursue in order to develop well-targeted policies and actions that finally intend to accelerate further eco-innovation. In the same vein, it should be noted that the analysis did not take into consideration which determinant may be relatively worthwhile to achieve desired outcomes. Even though *EdShare* has a higher relative potency in terms of its associated p-value than *FDI*, for instance, no conclusion can be drawn on what is best for a country. What might be interesting for politics to consider is the ease with which individual variables can be influenced. In that sense, it might be relatively easier and faster to influence demand for innovation by providing loan guarantees rather than raising a country’s education level.

5.3 Theoretical Contributions

In order to revisit the study’s original theoretical motivation, it is emphasised that the research conducted aims to shed light on the drivers of environment-related national innovation activity. Based on theoretical grounds of ideas-driven endogenous growth theory and the national innovation system perspective, the research question was formulated whether factors in terms of institutional-, human capital and research-, infrastructure-, market sophistication-, and business sophistication conditions affect national eco-innovation output. Acknowledging constant growth of the environmental goods and services industry which consequently gains in importance for overall national economic development, the search of extant literature, however, revealed few studies that empirically investigate determinants of eco-innovation. By employing Triadic Patent Families in selected environment-related technologies as the dependent variable, this proxy holds considerable promise for closing the gap in regard to drivers of eco-innovation as it enables a well-targeted analysis of selected environmentally friendly technologies. Apart from credit availability and inward FDI, it was found that especially education plays a decisive role in explaining variation in national eco-innovation output. Showing consistency with the results of previous empirical studies, this research contributes to theory by improving more subtle dimensions of comprehension. That is to say, the study's results within the scope of national eco-innovation activity provide a more nuanced version compared to earlier studies' findings associated with a country's general innovation activity and, thus, strengthen those contributions made by previous authors. The study further constitutes a legitimate value-added contribution for assessing the framework assumptions of the Global Innovation Index (GII, 2018). This is because GII (2018) assumes the need for all five innovation conditions to be improved in order to strengthen a country's innovation capability. The analysis of this study, however, indicates that included factors of both, institutional- as well as infrastructural conditions seem to play less of a role in impacting eco-innovation output. Instead, it seems to be sufficient to enhance human capital-, market sophistication-, or business sophistication conditions to influence TPF in selected environment-related technologies. It follows from the above that the study challenges the understanding of existing theory within the NIS perspective in terms of the importance of a homogenous set of conditions for innovation across distinctive technology fields. That is, even though NIS theory assumes all five conditions to impact general national innovation activity, the study provides evidence that this does not necessarily hold for innovation activity in environment-related technologies. Even though these results bring resolution to the puzzle that inspired this study to begin with, it simultaneously raises new questions. As such, a final meaningful advance of this thesis is that it raises the question why only certain innovation conditions as proposed by the NIS perspective seem to determine environment-related innovation activity.

5.4 Limitations and Future Research

Even though important insights can be drawn from the results of the analysis, it is emphasised that the research conducted is not exempt from limitations. These may affect the generalisability of results and interpretative power of the study so that results should consequently be treated with caution. Simultaneously, they may open up fruitful future research opportunities.

As was discussed, the utilisation of OECD Triadic Patent Families offers an improved measure of innovative performance at international level (Dernis & Khan, 2004). Nevertheless, the study acknowledges that this approach is still imperfect in specifying the extent of national innovation and recognises the pitfalls related to using patents as a proxy for innovative activity (Griliches, 1984, 1990; Pavitt, 1982, 1988; Trajtenberg, 1990). In keeping with past authors (Furman & Hayes, 2004; Furman, Porter, & Stern, 2002; Haščič & Migotto, 2015), it is explicitly referred to Griliches (1990, p. 1669) who concisely emphasizes that "not all inventions are patentable, not all inventions are patented, and the inventions that are patented differ greatly in 'quality', in the magnitude of inventive output associated with them".

Apart from patent counts in general, utilisation of TPF database by itself has its limitations in that, firstly, national innovative activity related to environmental technologies is possibly undercounted. Popp (2005) proposes a reason for this effect. Because the database only incorporates patents for which an application is filed at the EPO, JPO, and USPTO, the absence of a sales market for environmental innovation in one of the associated nations will understate innovation efforts. Reason for this is the lack of incentives for filing a patent. Especially, countries which decide to regulate first have fewer markets being available abroad for corresponding technologies developed. That is, no additional patents are filed in foreign countries with the result that inventions are not being considered in the TPF database and, thus, innovation levels being understated. Secondly, TPF data may be unbalanced insofar as the database is more likely to capture patents for product- rather than process innovations. According to Popp (2005), companies prefer to file patents for novel products rather than for new processes, as products will be released in the market making the loss of secrecy less problematic. The propensity of firms to conceal process innovations from the public is likely to cause this research of environment-related innovation to consider end-of-the-pipe treatment of pollution rather than modifications to production processes, for instance. Thirdly, TPF data is subject to the problem of timeliness with the result that the analysis conducted is limited to patent data up to and including the year 2013. Even though the time-lag between priority- and publication date already is a disadvantage for patent counts to single PTOs, it becomes even more of a drawback for TPF data. Among the multiple reference dates of patent documents, the priority date is the preferred date to measure innovation performance at a given point in time, because its closest to the original invention date. As such, the priority date is used for the computation of Triadic Patent Families. The limitation becomes manifest in an increased time lag since TPFs refer to multiple patent offices and, thus, potentially multiple priority dates of which the earliest is chosen (Dernis & Khan, 2004).

In the same vein, limitations of some of the independent variables under investigation should be highlighted. These reside in the fact that variables measuring for instance business freedom, education expenditures or trade openness are considered aggregated variables. Hence, their effects should be interpreted with caution. In order to yield more detailed and compelling results, future research should disaggregate aforementioned indicators. For example, education expenditures can be usefully split into the share of expenditures to secondary- and tertiary education.

The sample used in the study represents another source of limitation. By reason of data availability, only OECD member states are included in the analysis which implicates that these countries have comparatively high incomes. More precisely, 26 countries are considered high-income economies according to World Bank which finally challenges generalisability of the results to a broader population. Future research should include more observations from developing countries if data is available. Furthermore, it should be noted, that even though the focus on OECD member states offers more comprehensive data, a complete dataset is not achieved. To fill missing values, linear inter-/extrapolation techniques have been employed. Notwithstanding that resulting values tend to approach actual values this choice is not exempt from criticism as absolute accuracy is not assumed.

Considering employed estimation method, the fixed effects model chosen to analyse which factors explain variation in TPF-ENVTECH, only models within variation. Between variation is not modelled, but rather taken as given. That is, the question of why some countries reveal generally higher levels of environment-related innovation activity is neglected in the analysis. Further research should be undertaken to analyse between variations in eco-innovation activity.

Referring to theory of the national innovation system perspective, the framework developed in this study is comprehensive in terms of dimension coverage since institutional-, human capital and research-, infrastructural-, market sophistication-, as well as business sophistication conditions, are covered. Still, it should be acknowledged that because of data availability the analysis merely takes into consideration a fraction of relevant dimension factors that might influence environment-related innovation activity. Hence, future research is advised to capture a wider spectrum of individual variables to provide a more complete picture of environment-related innovation drivers.

Finally, the framework in combination with employed methodology was specifically designed to explain relevant innovation factors independently. However, theory of the national innovation system perspective proposes that the rationale of innovation drivers is best understood in the form of combinations. As such, the thesis is not able to provide a comprehensive framework in terms of interlinkages and interdependences between individual factors. A more systemic view is needed to examine configurational conditions which open up interesting research possibilities for future studies to ultimately provide a deeper understanding of innovation drivers.

6. Conclusion

A large body of literature broadly acknowledges the importance of innovation in being a driving force for national economic development and, with it, for general social welfare. Triggered by global climate changes, the development of environmentally friendly technologies and services has transformed into a growing industry, hence, gaining in influence not only on environmental protection but also on sustainable economic development. Still, empirical research specifically investigating drivers of environment-related innovation seems to be in its infancy. Simultaneously, existing research appears to be rather fragmented concerning coverage of relevant dimensions of innovation drivers. Motivated by this important gap, the thesis builds on theoretical grounds of ideas-driven endogenous growth theory and the national innovation system perspective and develops a comprehensive framework to answer the research question of what institutional-, human capital and research-, infrastructural-, market sophistication-, as well business sophistication conditions influence eco-innovation output. Referring to Triadic Patent Families in selected environment-related technologies, the study makes use of an empirical operationalisation of eco-innovation that improves international comparability compared to commonly used patent counts from single patent offices. Analysing a panel of 28 OECD countries concerned over the period 1998 – 2013 using fixed effects regression models, empirical results indicate that human capital-, market sophistication-, and business sophistication conditions seem to play a role in determining national environment related innovation performance. Particularly, evidence is found that educational factors, credit availability to the private sector and inward foreign direct investments significantly explain the variation of the number of TPFs in selected environment-related technologies. In contrast, no evidence was found for a significant impact of factors pertaining to institutional- as well as infrastructural innovation conditions. Even though the analysis is not exempt from limitations, generally, findings have relevant implications for policy-making. Policymakers should pursue both, supply- as well as demand side approaches to develop policies and actions subtly tailored to effectively nurture eco-innovation. Simultaneously, limitations arise as a pathway for future research suggesting a more in-depth analysis of configurational conditions to better understand the interlinkages between specific factors and provide a more comprehensive picture of the complex system of innovation drivers.

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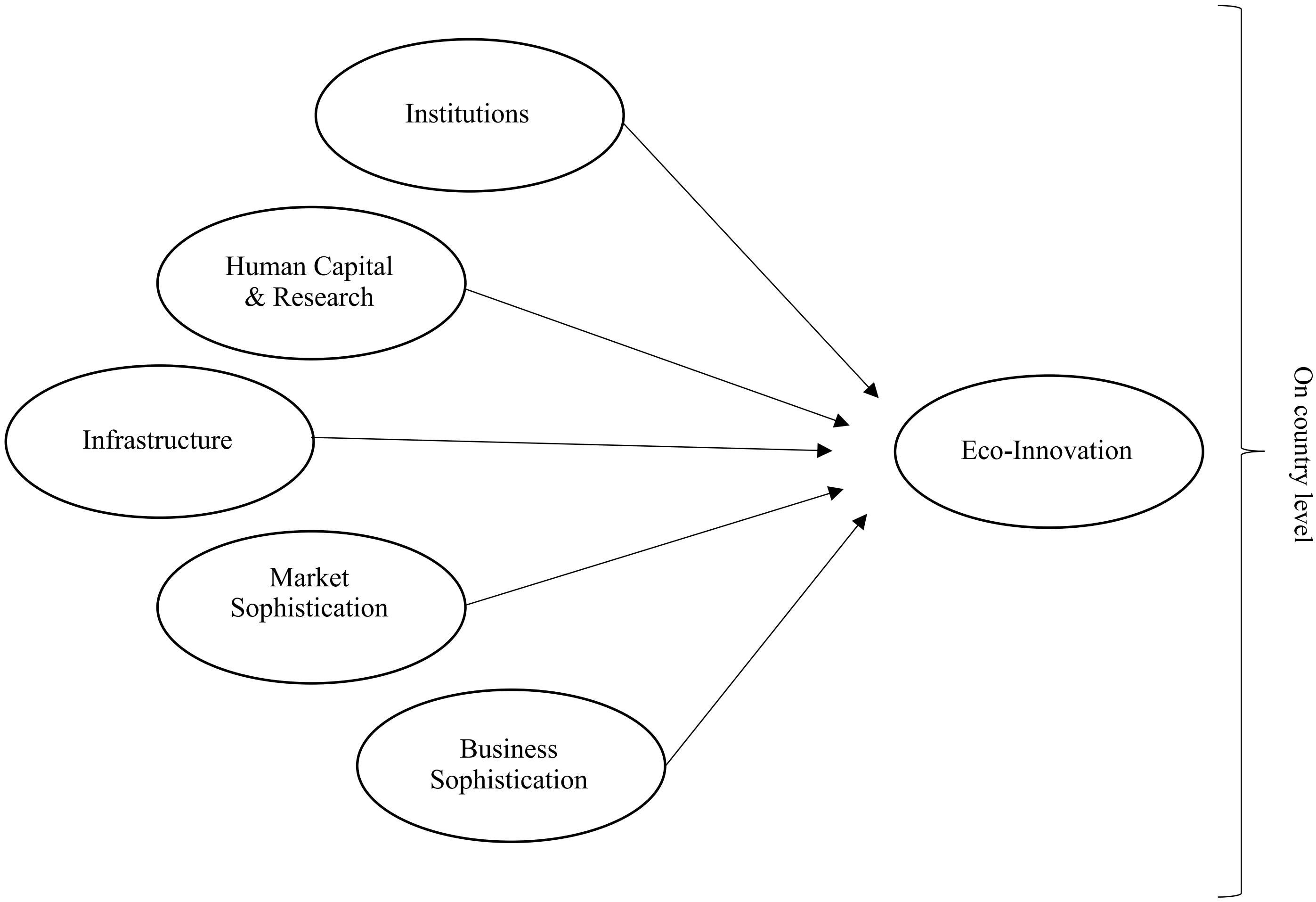
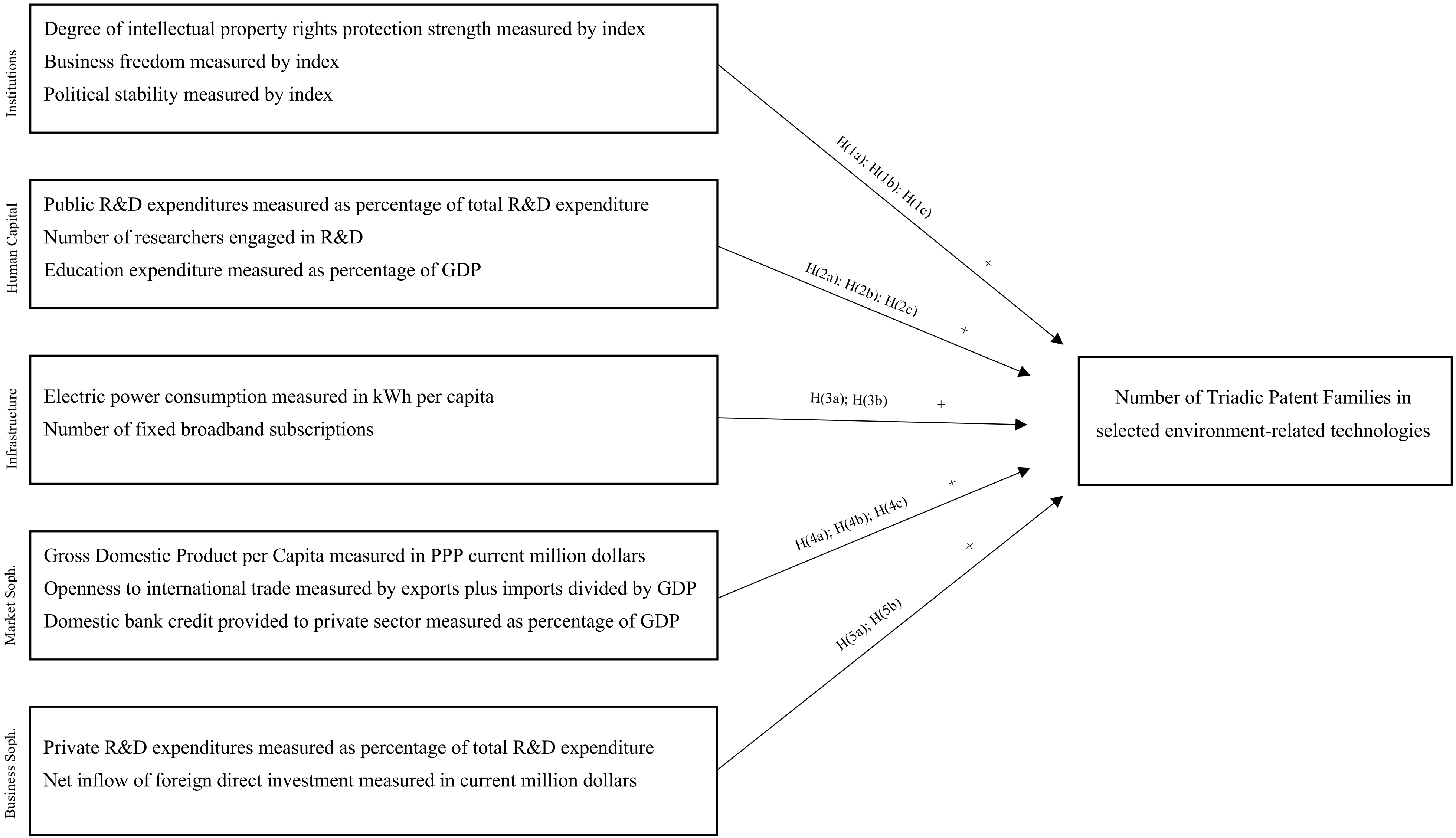
Appendix A – Conceptual Framework



Appendix B – Theoretical Framework



Appendix C – Variables and Definitions

Variables and definitions

Label	Variable	Full Variable Name	Definition/Measure	Data Source
Environmental Innovation				
$\boldsymbol{TPF - ENVTECH_i}$	Triadic Patent Families	Triadic Patent Families in selected environment-related technologies	Number of patents filed at the European Patent Office, Japan Patent Office, US Patent and Trademark Office	OECD Main Science and Technology Indicators (MSTI)
Institutions $\boldsymbol{U^{INST}}$				
$\boldsymbol{IPR_{it}}$	Intellectual Property Rights	Degree of intellectual property rights protection strength	Index Rating 0 – 100	Heritage Foundation
$\boldsymbol{BusFree_{it}}$	Business Freedom	Business Freedom	Index Rating 0 – 100	Heritage Foundation
$\boldsymbol{PolStab_{it}}$	Political Stability	Political stability and absence of violence/terrorism: estimate	Likelihood of political instability and/or politically-motivated violence measured in units ranging from −2.5 to +2.5	World Governance Indicators (World Bank)
Human Capital & Research $\boldsymbol{V^{HUM}}$				
$\boldsymbol{PublRD_{it}}$	Public R&D Expenditure	Percentage of GERD financed by government	Public R&D expenditure divided by total R&D expenditure	OECD Main Science and Technology Indicators (MSTI)
$\boldsymbol{PersRD_{it}}$	R&D Personnel	Personnel employed in R&D	Number of researchers engaged in R&D as per millions of people	World Bank Group
$\boldsymbol{EdShare_{it}}$	Education Expenditure	Share of GDP spent on education	General government expenditure on education (current, capital, and transfers) expressed as a percentage of GDP	World Bank Group

Label	Variable	Full Variable Name	Definition/Measure	Data Source
Infrastructure W^{INFR}				
$GenInfr_{it}$	General Infrastructure	Electric power consumption (kWh per capita)	Production of power plants and combined heat and power plants in kilowatt hour (kWh) divided by midyear population	World Bank Group
$ICTInfr_{it}$	Broadband Network Infrastructure	Fixed broadband subscriptions	Fixed subscriptions to high-speed access to the public Internet (a TCP/IP connection)	World Bank Group
Market Sophistication X^{MARK}				
$GDPCap_{it}$	GDP per Capita	Gross Domestic Product per capita	PPP current international dollars in millions	World Development Indicators (World Bank)
$Openness_{it}$	Trade Openness	Openness to international trade	Trade as percentage of GDP measured by exports plus imports divided by GDP	World Development Indicators (World Bank)
$Credit_{it}$	Credit Availability	Domestic credit to private sector (% of GDP)	Financial resources provided to the private sector by financial corporations as percentage of GDP	World Development Indicators (World Bank)
Business Sophistication				
$PrivRD_{it}$	Private R&D Expenditures	Percentage of GERD financed by the business enterprise sector	Private R&D expenditure divided by total R&D expenditure	OECD Main Science and Technology Indicators (MSTI)
FDI_{it}	Net Inflow FDI	Foreign direct investment, net inflows	BoP (Balance of Payments) current million US$	World Bank Group
Control Variables				
$EdLevel_{it}$	Education Level	Mean years of schooling	Average number of years of education received by population aged 25+	United Nations Human Development Reports
$Popul_{it}$	Population	Population size	Number of Persons in thousands	OECD Main Science and Technology Indicators (MSTI)

Appendix D – Pair-wise Correlations

Pair-wise Correlations

		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	zIPR	1.0000													
2	zBusFree	0.4952	1.0000												
3	zPolStab	0.5314	0.2632	1.0000											
4	zPublRD	-0.5499	-0.4132	-0.1438	1.0000										
5	zPersRD	0.6485	0.5024	0.3848	-0.6035	1.0000									
6	zEdShare	0.4159	0.4043	0.2920	-0.2347	0.6099	1.0000								
7	zGenInfr	0.5053	0.3355	0.4297	-0.3074	0.7133	0.4647	1.0000							
8	zICTInfr	0.3130	0.5686	0.0695	-0.2975	0.5657	0.3428	0.3237	1.0000						
9	zGDPCap	0.6000	0.4708	0.3961	-0.5505	0.5957	0.2315	0.5108	0.6106	1.0000					
10	zOpenness	0.1827	0.1361	0.3469	-0.3386	0.1007	-0.0824	0.0872	0.1523	0.4927	1.0000				
11	zCredit	0.5569	0.5271	0.2518	-0.2837	0.5358	0.4280	0.3966	0.5168	0.4975	-0.0968	1.0000			
12	zPrivRD	0.4958	0.3682	0.3316	-0.7373	0.5238	0.2148	0.2595	0.2189	0.4661	0.3204	0.2184	1.0000		
13	zFDI	0.2058	0.1881	0.0060	-0.1150	0.0160	-0.0427	-0.0721	0.2620	0.1818	0.0048	0.1928	0.0809	1.0000	
14	zEdLevel	0.4855	0.4465	0.3415	-0.4470	0.5126	0.4024	0.2465	0.4811	0.4405	0.2710	0.2796	0.3450	0.1475	1.0000

Strongly balanced panel of 28 OECD countries over a period from 1998 to 2013

Appendix E – Descriptive Statistics

Descriptive Statistics

Variable	Mean	Std. Dev.	Min	Max	Observations
TPF – ENVTECH	56.17082	128.5626	0	745.0106	448
IPR	76.36161	15.13692	40	95	448
BusFree	78.45201	10.47591	53.7	100	448
PolStab	.7665566	.7047253	-1.626286	1.987729	448
PublRD	38.13487	12.38211	.1853254	70.69022	448
PersRD	3344.508	1813.418	209.0888	9214.556	448
EdShare	5.222521	1.241261	.9223546	8.55955	448
GenInfr	9021.736	7722.726	1520.098	54799.17	448
ICTInfr	14.37947	12.42715	.0002374	40.33326	448
GDPCap	30555.85	13484.45	8358.779	95590.54	448
Openness	94.695	53.88103	37.15629	349.2419	448
Credit	87.52704	45.86275	.1858704	312.0269	448
PrivRD	48.7823	12.6374	16.51046	90.68425	448
FDI	27944.47	57848.42	-29679.43	734010.3	448
EdLevel	10.88415	1.76412	5.3	14	448

Strongly balanced panel of 28 OECD countries over a period from 1998 to 2013

Appendix F – Variance Inflation Factors (VIF)

Variance Inflation Factors

Variable	VIF	1/VIF
zPersRD	5.64	0.177205
zGDPCap	4.45	0.224563
zPublRD	3.95	0.252898
zIPR	3.53	0.283097
zICTInfr	3.52	0.283793
zGenInfr	2.72	0.367323
zPrivRD	2.51	0.398800
zPolStab	2.49	0.402711
zOpenness	2.46	0.406221
zCredit	2.29	0.437579
zEdLevel	2.05	0.488105
zBusFree	2.04	0.489384
zEdShare	1.85	0.539137
zFDI	1.26	0.796449
Mean VIF	2.91	

Appendix G – Hypotheses

Hypotheses

Label	Hypothesis	Expected Sign	Considered Variable	Supported
H(1a)	The stronger intellectual property rights protection is, the higher environment-related patenting output.	+	IPR	No
H(1b)	The more favourable conditions for starting a business are, the higher environment-related patenting output.	+	BusFree	No
H(1c)	The more stable the political environment of a country is, the higher environment-related patenting output.	+	PolStab	No
H2	The higher (a) public R&D expenditure, (b) public education expenditure and (c) the number of research personnel is, the higher environment-related patenting output.	+	PublRD, PersRD, EdShare	Partially
H(3a)	The greater electricity consumption is, the higher environment-related patenting output.	+	GenInfr	No
H(3b)	The better access to ICTs is, the higher environment-related patenting output.	+	ICTInfr	No
H(4a)	The larger the market scale of an economy is, the higher environment-related patenting output.	+	GDPCap	No
H(4b)	The more open an economy is to international trade, the higher environment-related patenting output.	+	Openness	No
H(4c)	The better the availability of credit to the private sector is, the higher environment-related patenting output.	+	Credit	Yes
H5	The higher (a) private R&D funding and (b) inward foreign direct investment is, the higher environment-related patenting output.	+	PrivRD, FDI	Partially

Appendix H – Robustness Checks

Estimation robustness checks taking Model (4) as benchmark

Independent Variable	Robust (1) time lag (t-1)	Robust (2) reduced sample (PRT, SWE)	Robust (3) variable swap (FTERD)	Robust (4) add. covariate (Popul)
IPR	0.168	-0.242	-0.126	-0.143
	(0.110)	(0.172)	(0.160)	(0.153)
BusFeee	-0.144	-0.105	-0.125	-0.116
	(0.084)	(0.085)	(0.078)	(0.084)
PolStab	0.083	0.156	0.070	0.077
	(0.245)	(0.182)	(0.189)	(0.188)
PublRD	-0.027	0.203	0.118	0.117
	(0.130)	(0.136)	(0.142)	(0.147)
PersRD	0.037	0.128	-	0.109
	(0.189)	(0.254)		(0.209)
FTERD	-	-	0.126	-
			(0.230)	
EdShare	0.366***	0.303**	0.278**	0.289**
	(0.133)	(0.143)	(0.131)	(0.138)
GenInfr	-0.000	-0.039	-0.033	-0.050
	(0.083)	(0.098)	(0.117)	(0.107)
ICTInfr	-0.029	-0.132	-0.128	-0.139
	(0.192)	(0.203)	(0.180)	(0.196)
GDPCap	0.260	0.374	0.457	0.458
	(0.357)	(0.373)	(0.362)	(0.368)
Openness	-0.384	-0.277	-0.345	-0.353
	(0.259)	(0.348)	(0.345)	(0.360)
Credit	0.370**	0.351**	0.338*	0.343*
	(0.158)	(0.168)	(0.165)	(0.168)
PrivRD	0.060	0.109	0.153	0.165
	(0.090)	(0.119)	(0.113)	(0.112)
FDI	0.035*	0.041**	0.034*	0.033*
	(0.020)	(0.019)	(0.018)	(0.018)
EdLevel	0.418*	0.262*	0.292*	0.305*
	(0.235)	(0.136)	(0.158)	(0.167)
Popul	-	-	-	-0.366
				(0.720)
Constant	2.497***	2.560***	2.513***	2.541***
	(0.031)	(0.030)	(0.031)	(0.043)
N (observations)	354	328	354	354
N (groups)	28	26	28	28
R^2: (within)	0.185	0.176	0.174	0.174
(between)	0.347	0.194	0.342	0.112
(overall)	0.365	0.240	0.351	0.145
F-Test (p-value)	0.000	0.000	0.000	0.000
LM-Test (p-value)	0.000	0.000	0.000	0.000
Hausman Test (p-value)	0.025	0.014	0.000	0.000
Wald: H0 homoskedast.	15576.49***	15525.83***	12493.95***	13099.74***
Wooldr: H0 no serial corr.	1.909	1.130	1.421	1.275
Pesar: H0 cross-sect. dep.	3.422***	4.642***	3.663***	3.488***

Fixed effects estimation of models (1), (2), (3), and (4). A balanced panel of 28 countries covering the period from 1998 to 2013 is used. Standard errors (robust to heteroscedasticity) are in parentheses.
(Two-tailed) significance levels: *10%; **5%; ***1%

Declaration of Originality

I hereby certify that I am the sole author of this Work Project for the International Master in Management. The views and arguments provided in this thesis reflect my opinion, and not necessarily that of Statistics Portugal.

I certify that, to the best of my knowledge, my work project does not infringe upon anyone's copyright nor violate any proprietary rights. Any ideas, techniques, quotations, or any other material from the work of other people included in my thesis, published or otherwise, are fully acknowledged in accordance with the standard referencing practices.

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Maastricht, 17th of December 2018